

RADIO ENGINEERING and ELECTRONIC PHYSICS

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UTILIZATION OF KIRCHHOFF'S APPROXIMATION IN THE PROBLEM OF THE SCATTERING OF RADIO WAVES BY PERIODICALLY ROUGH SURFACES WITH FINITE CONDUCTIVITY

V.I. Aksenov

On the basis of the Huygens-Kirchhoff principle and of the approximations from geometrical optics, solutions to the problem of the scattering of radio waves by a limited region of double sinusoidal (undulation in two directions), and sawtooth surfaces with finite conductivity are obtained. These solutions can be used in the analysis of the scattered field in the far zone.

The solution for a sawtooth surface is obtained in a finite form; for a double sinusoidal surface, it is in the form of a rapidly converging series.

Examples of the analysis of the scattering of waves by the indicated surfaces are examined.

INTRODUCTION

Of the problems concerning the scattering of electromagnetic waves by periodically rough surfaces, a number of questions connected with scattering by surfaces with a finite conductivity have been little studied.

An effective approximation method for the analysis of the field, scattered by periodically rough surfaces, is the method based on the use of the Huygens-Kirchhoff principle and an approximation from geometrical optics. It was first utilized for rough ideally conducting surfaces by Brekhovskikh [1], and then extended to the case of surfaces with a finite conductivity in the work [2].

In the author's work [3] with the Kirchhoff approximation, the solution to the problem of the scattering of electromagnetic waves by a limited region of sinusoidal or of trochoidal (undulation in one direction) surfaces with a finite conductivity, permitting calculation of the scattered field in the far zone, was obtained. The method utilized for the solution consisted of the expansion of the periodical part of the expression under the integral sign in Kirchhoff's formula into a Fourier series and a subsequent integration by parts. It is shown below that one may solve a more complicated three-dimensional problem on the scattering of waves by a double sinusoidal surface with finite conductivity by an analogous method.

At the same time, the utilization of the method based on the expansion of the expression under the integral into a Fourier series is not always practical. It is shown by the example of a sawtooth surface that in the case of a simple type of roughness the Kirchhoff integral, written in accordance with a geometrical optics approximation, may be obtained in its finite form.

1. INITIAL EXPRESSIONS

In the author's work [3] expressions for the field in the far zone, scattered by a limited region with a periodically rough surface with finite conductivity were obtained on the basis of

Kirchhoff's approximation {see [3], formulas (6), (8)} There it was assumed that the scattering surface undulates in only one direction.

In the present work the indicated expressions are generalized for the case of periodically rough surfaces, undulating in two directions, the equations of which are given in the form $z = Z(x, y)$.

Considering that the wave vector which is incident on the surface of a plane monochromatic wave and the observation point P are in the xz plane, we have the following formulas for the scattered field in the far zone, for the case of surfaces with finite conductivity, undulating in two directions.

a) Vertical polarization (The electric vector of the incident wave lies in the xz plane):

$$\vec{E}(P) = j \frac{E_0}{\lambda} \frac{e^{-jkR}}{R} \int_S \{ (-\vec{i} \cos \alpha + \vec{k} \sin \alpha) [(1 + p \cos \theta) (-n_z \cos \alpha - n_x \sin \alpha + p) - pn_y^2 (1 + \cos(\tau - \alpha))] - \vec{j} pn_y [n_x (\cos \tau + \cos \alpha) - n_z (\sin \tau + \sin \alpha) + p \sin(\tau - \alpha)] \} \times \frac{\cos \theta}{(1 + p \cos \theta)(\cos \theta + p)} \exp \{ jk [x (\sin \tau + \sin \alpha) + Z(x, y) (\cos \tau + \cos \alpha)] \} dS, \quad (1)$$

where τ and α are correspondingly the angles of incidence and of scattering, measured from the z axis, $p = \sqrt{\mu^*/\epsilon^*}$ (μ^* and ϵ^* are the relative complex permeability and permittivity of the scattering surface); n_x , n_y and n_z are the components of the unit vector $\vec{n}$ of the internal normal to the surface; $\cos \theta = -(\vec{n} \vec{k}_0)$ ($\vec{k}_0$ is the unit wave vector of the incident wave).

b) Horizontal polarization (The electric vector is perpendicular to the xz plane);

$$\vec{E}(P) = j \frac{E_0}{\lambda} \frac{e^{-jkR}}{R} \int_S \{ (-\vec{i} \cos \alpha + \vec{k} \sin \alpha) n_y [-\sin(\tau - \alpha) - pn_z (\sin \tau + \sin \alpha) - pn_x (\cos \tau + \cos \alpha)] - \vec{j} [(\cos \theta + p) (1 - pn_x \sin \alpha - pn_z \cos \alpha) - pn_y^2 (1 + \cos(\tau - \alpha))] \} \times \frac{\cos \theta}{(1 + p \cos \theta)(\cos \theta + p)} \exp \{ jk [x (\sin \tau + \sin \alpha) + Z(x, y) (\cos \tau + \cos \alpha)] \} dS. \quad (2)$$

In the derivation of expressions (1), (2) the conditions were the same as in [3]. In part, it was assumed that the linear dimensions of the scattering surface (which is chosen in the form of a rectangle with sides d and e) are much greater than the wavelength of the incident wave λ and the periods of the unevennesses, and that the magneto-dielectric parameters of the surface obey the inequality $|\mu^* \epsilon^*| \gg 1$.

2. SCATTERING OF ELECTROMAGNETIC WAVES BY A DOUBLE SINUSOIDAL SURFACE

Let the double sinusoidal surface be described by the relation $Z(x, y) = -a \cos Kx \cos K'y$, where a is the amplitude of the undulation; $K = 2\pi/\Lambda$; $K' = 2\pi/\Lambda'$.

Substituting into (1) the components of the normal $\vec{n}$, after the substitution of the variables $\xi = Kx$, $\eta = K'y$, we will obtain for the case of vertical polarization

$$\vec{E}(P) = j \frac{E_0}{\lambda K K'} \frac{e^{-jkR}}{R} \int_{-\frac{\pi d}{\Lambda}}^{\frac{\pi d}{\Lambda}} \int_{-\frac{\pi l}{\Lambda'}}^{\frac{\pi l}{\Lambda'}} \{ (-\vec{i} \cos \alpha + \vec{k} \sin \alpha) f_{1v}(\xi, \eta) + \vec{j} f_{2v}(\xi, \eta) \} \times \exp(j\beta\xi - j\gamma \cos \xi \cos \eta) d\xi d\eta. \quad (3)$$

where $\beta = \frac{\lambda}{\Lambda} (\sin \tau + \sin \alpha)$; $\gamma = ka (\cos \tau + \cos \alpha)$; $f_{1v}(\xi, \eta)$, $f_{2v}(\xi, \eta)$ are the periodic functions of ξ and η , obtained from the expressions

$$\begin{aligned}
 f_{1V} &= \frac{\{(1 + p \cos \theta)(-n_z \cos \alpha - n_x \sin \alpha + p) - p n_y^2 [1 + \cos(\tau - \alpha)]\} \cos \theta}{n_z (1 + p \cos \theta) (\cos \theta + p)}; \\
 f_{2V} &= \frac{-p n_y [n_x (\cos \tau + \cos \alpha) - n_z (\sin \tau + \sin \alpha) + p \sin(\tau - \alpha)] \cos \theta}{n_z (1 + p \cos \theta) (\cos \theta + p)}; \\
 n_x &= -n_z a K \sin \xi \cos \eta; \\
 n_y &= -n_z a K' \cos \xi \sin \eta; \\
 n_z &= \frac{1}{\sqrt{1 + (K a \sin \xi \cos \eta)^2 + (K' a \cos \xi \sin \eta)^2}}.
 \end{aligned} \tag{4}$$

We will also obtain expressions of the form (3) for horizontal polarization of the incident wave. In this case, the functions f_{1V} , f_{2V} are replaced by the following:

$$\begin{aligned}
 f_{1g} &= \frac{n_y [-\sin(\tau - \alpha) + p n_z (\sin \tau + \sin \alpha) - p n_x (\cos \tau + \cos \alpha)] \cos \theta}{n_z (1 + p \cos \theta) (\cos \theta + p)}, \\
 f_{2g} &= \frac{-\{(\cos \theta + p)(1 - p n_x \sin \alpha - p n_z \cos \alpha) - p n_y^2 [1 + \cos(\tau - \alpha)]\} \cos \theta}{n_z (1 + p \cos \theta) (\cos \theta + p)}.
 \end{aligned} \tag{5}$$

It follows from expression (3) that in the general case the field in the far zone, scattered by a periodically rough surface, undulating in two directions and having a finite conductivity, will have the form of an elliptically polarized wave, if the incident wave is linearly polarized. It is necessary to determine the integral of the following form for the calculation of the indicated field:

$$I = \int_{-\frac{\pi d}{\Lambda}}^{\frac{\pi d}{\Lambda}} \int_{-\frac{\pi l}{\Lambda'}}^{\frac{\pi l}{\Lambda'}} f(\xi, \eta) \exp(j\gamma \xi - j\gamma \cos \xi \cos \eta) d\xi d\eta, \tag{6}$$

where $f(\xi, \eta)$ is the periodic function of ξ, η .

In order to determine the integral (6), let us expand the periodic part of the expression under the integral into a double Fourier series, after which let us perform an integration by parts, having previously substituted the limits of integration as $\pm \pi D$ and $\pm L$, where D and L are respectively the nearest integers to d/Λ and l/Λ' .¹

Let us write down the expansion into a double Fourier series for the function $e^{-j\gamma \cos \xi \cos \eta}$.

In accordance with the equality $\cos \xi \cos \eta = \frac{1}{2} [\cos(\xi + \eta) + \cos(\xi - \eta)]$ and with the known expansion into a series of Bessel functions, we will obtain for the expression in the form $e^{-j\xi \cos \eta}$

$$\begin{aligned}
 e^{-j\gamma \cos \xi \cos \eta} &= \frac{1}{4} \sum_{k, l=0}^{\infty} \varepsilon_k \varepsilon_l (-j)^{k+l} J_k\left(\frac{\gamma}{2}\right) J_l\left(\frac{\gamma}{2}\right) [e^{j\xi(k+l)} e^{j\eta(l-k)} + \\
 &+ e^{j\xi(k-l)} e^{-j\eta(k+l)} + e^{j\xi(l-k)} e^{j\eta(k+l)} + e^{-j\xi(k+l)} e^{j\eta(k-l)}] \\
 &(\varepsilon_n = 1 \text{ when } n = 0, \quad \varepsilon_n = 2 \text{ when } n \neq 0).
 \end{aligned} \tag{7}$$

Substituting into (6) for the function $f(\xi, \eta)$ and $e^{-j\gamma \cos \xi \cos \eta}$ their equivalent double Fourier series, and performing the integrations in ξ and η we will obtain for I

$$\begin{aligned}
 I &= \pi^2 L D \sum_{m=0}^{\infty} \left\{ \lambda_{m0} J_0^2\left(\frac{\gamma}{2}\right) \left[(C_{m0} + D_{m0}) \frac{\sin \pi D (\beta + m)}{\pi D (\beta + m)} + \right. \right. \\
 &\quad \left. \left. + (C_{m0}^* + D_{m0}^*) \frac{\sin \pi D (\beta - m)}{\pi D (\beta - m)} \right] + \right.
 \end{aligned}$$

¹See [4] and [3] for the explanation of such a substitution.

$$\begin{aligned}
& + \sum_{\substack{k, n=0 \\ (n \geq k; k \geq n)}}^{\infty} \lambda_{mn} \varepsilon_k \varepsilon_{|n-k|} \Delta_{kn} J_k \left(\frac{\gamma}{2} \right) J_{|n-k|} \left(\frac{\gamma}{2} \right) \times \\
& \times \left[C_{mn} \frac{\sin \delta_{221}}{\delta_{221}} + D_{mn} \frac{\sin \delta_{212}}{\delta_{212}} + D_{mn}^* \frac{\sin \delta_{121}}{\delta_{121}} + C_{mn}^* \frac{\sin \delta_{112}}{\delta_{112}} \right] + \\
& + \sum_{\substack{k, n=0 \\ (k \geq n)}}^{\infty} \lambda_{mn} \varepsilon_k \varepsilon_{k+n} (-j)^{2k+n} J_k \left(\frac{\gamma}{2} \right) J_{n+k} \left(\frac{\gamma}{2} \right) \times \\
& \times \left[C_{mn} \frac{\sin \delta_{211}}{\delta_{211}} + D_{mn} \frac{\sin \delta_{232}}{\delta_{222}} + D_{mn}^* \frac{\sin \delta_{111}}{\delta_{111}} + C_{mn}^* \frac{\sin \delta_{122}}{\delta_{122}} \right] \} \\
& \left(\lambda_{00} = \frac{1}{4}, \quad \lambda_{m0} = \lambda_{0n} = \frac{1}{2} \text{ and } \lambda_{mn} = 1 \quad \text{when } m > 0, n > 0 \right),
\end{aligned} \tag{8}$$

where C_{mn} , D_{mn} are the coefficients of the Fourier function $f(\xi, \eta)$:

$$\begin{aligned}
C_{mn} &= \frac{1}{4\pi^2} \int_{-\pi}^{+\pi} \int_{-\pi}^{+\pi} f(\xi, \eta) e^{-j(m\xi + n\eta)} d\xi d\eta; \\
D_{mn} &= \frac{1}{4\pi^2} \int_{-\pi}^{+\pi} \int_{-\pi}^{+\pi} f(\xi, \eta) e^{-j(m\xi - n\eta)} d\xi d\eta;
\end{aligned}$$

C_{mn}^* , D_{mn}^* are the complex conjugates of C_{mn} , D_{mn} :

$$\begin{aligned}
\delta_{pqr} &= \pi D [\beta + m(-1)^p + 2k(-1)^q + n(-1)^r]; \\
\Delta_{kn} &= \begin{cases} (-j)^n & \text{when } n \geq k; \\ (-1)^{k-n} (-j)^n & \text{when } k \geq n. \end{cases}
\end{aligned}$$

The solution obtained permits the calculation of the amplitude of the wave scattered by a double sinusoidal surface with finite conductivity.

Under the above assumption that the wave vector of the incident wave and the observation point are situated in the xz plane, the direction of the maxima of the scattering lobes are determined from the values $\beta = N (N = 0, \pm 1, \pm 2, \dots)$. Here, the members of the series (8) will be nonzero only when $\delta_{pqr} = 0$.

Since the series (8) converge sufficiently rapidly in the case of a double sinusoidal surface, the amplitude of the scattered field at the maximum of each lobe may be determined by the summation of a small number of nonzero terms.

The case of reflection from a mirror ($\beta = 0$), is of great practical interest. When $\beta = 0$, the formula (8) is greatly simplified and becomes more convenient for calculations:

$$\begin{aligned}
I_{\beta=0} &= I_0 = \pi^2 LD \left\{ J_0^2 \left(\frac{\gamma}{2} \right) \frac{a_{00}}{2} + \right. \\
& + \sum_{\substack{m, s=0 \\ (m \geq 2s)}}^{\infty} \lambda_{m, m+2s} \varepsilon_s \varepsilon_{m+s} (-j)^{m+2s} J_s \left(\frac{\gamma}{2} \right) J_{m+s} \left(\frac{\gamma}{2} \right) a_{m, m+2s} + \\
& + \sum_{\substack{m, s=0 \\ (m \geq 2s)}}^{\infty} \lambda_{m, m-2s} \varepsilon_s \varepsilon_{m-s} (-j)^m J_s \left(\frac{\gamma}{2} \right) J_{m-s} \left(\frac{\gamma}{2} \right) a_{m, m-2s} \left. \right\},
\end{aligned} \tag{9}$$

where a_{mn} is the Fourier coefficient, equal to

$$a_{mn} = \frac{1}{\pi^2} \int_{-\pi}^{+\pi} \int_{-\pi}^{+\pi} f(\xi, \eta) \cos m\xi \cos n\eta d\xi d\eta.$$

The solution obtained permits the transition to the extreme case of an ideally conducting surface ($p = 0$).

When $p = 0$ the corresponding Fourier coefficients will be equal to [see (4) and (5)]:

For the function f_{1v} $C_{00} = D_{00} = -\cos \alpha$, $C_{11} = D_{11} = -jaK \sin \alpha$; (10)

For the function f_{lg} $C_{11} = D_{11} = -jaK' \sin(\tau - \alpha)$;

For the function f_{2g} $C_{00} = D_{00} = -\cos \tau$, $C_{11} = D_{11} = -jaK \sin \tau$ (11)

(all the remaining Fourier coefficients will be zero).

After the substitution of (10) and (11) into (8), in accordance with (3) we will obtain for the electric field in the far zone, scattered by an ideally conducting double sinusoidal surface: in the case of vertical polarization

$$\vec{E}(P) = j \frac{2\pi^2 L D E_0}{\lambda K K'} \frac{e^{-jkR}}{R} \left\{ (-i \cos \alpha + k \sin \alpha) \left[-\cos \alpha \sum_{k=0}^{\infty} \varepsilon_k (-1)^k J_k^2 \left(\frac{\gamma}{2} \right) \times \right. \right. \\ \left. \times \left(\frac{\sin \delta_2}{\delta_2} + \frac{\sin \delta_1}{\delta_1} \right) + \frac{a K \sin \alpha}{\gamma} \sum_{k=0}^{\infty} \varepsilon_k (-1)^k J_k^2 \left(\frac{\gamma}{2} \right) 2k \left(\frac{\sin \delta_2}{\delta_2} - \frac{\sin \delta_1}{\delta_1} \right) \right] \right\}, \quad (12)$$

где

$$\delta_q = \pi D \{ \beta + 2k(-1)^q \};$$

in the case of horizontal polarization

$$\vec{E}(P) = j \frac{2\pi^2 L D E_0}{\lambda K K'} \frac{e^{-jkR}}{R} \left\{ (-i \cos \alpha + k \sin \alpha) \frac{a K' \sin(\tau - \alpha)}{\gamma} \times \right. \\ \times \sum_{k=0}^{\infty} \varepsilon_k (-1)^k J_k^2 \left(\frac{\gamma}{2} \right) 2k \left(\frac{\sin \delta_2}{\delta_2} - \frac{\sin \delta_1}{\delta_1} \right) - \\ - j \left[-\cos \tau \sum_{k=0}^{\infty} \varepsilon_k (-1)^k J_k^2 \left(\frac{\gamma}{2} \right) \left(\frac{\sin \delta_2}{\delta_2} + \frac{\sin \delta_1}{\delta_1} \right) + \right. \\ \left. + \frac{a K \sin \tau}{\gamma} \sum_{k=0}^{\infty} \varepsilon_k (-1)^k J_k^2 \left(\frac{\gamma}{2} \right) 2k \left(\frac{\sin \delta_2}{\delta_2} - \frac{\sin \delta_1}{\delta_1} \right) \right] \right\}. \quad (13)$$

Substituting into the expressions (12) and (13) $\tau = \alpha$, we will obtain as a special case the formula for the reverse scattering of electromagnetic waves, described in [4].

3. SCATTERING OF ELECTROMAGNETIC WAVES BY A SAWTOOTH SURFACE

Let us examine the scattering of electromagnetic waves by a limited region of a sawtooth surface, which is described by the relation (Figure 1)

$$z = \pm 4a \left[\frac{x}{\Lambda} - \left(n \mp \frac{1}{4} \right) \right], \\ n = 0, \pm 1, \pm 2, \dots$$

[the upper sign is taken when $(n - \frac{1}{2})\Lambda \leq x \leq n\Lambda$; the lower sign when $n\Lambda \leq x \leq (n + \frac{1}{2})\Lambda$].

It follows from Figure 1 that

$$n_z = \cos \kappa = \frac{1}{\sqrt{1 + \left(\frac{4a}{\Lambda} \right)^2}}, \quad n_x = \mp \frac{4a}{\Lambda} \cos \kappa, \quad n_y = 0, \\ \theta = \tau \pm \kappa, \quad dS = \frac{dx dy}{\cos \kappa}. \quad (14)$$

We will accomplish the determination of the integrals (which we will call I) in expressions (1) and (2) for the examined case in the following manner: we will perform the integration over the regions which correspond to separate boundaries (half-periods) of the surface, and then will perform a summation of the results obtained.

Let us assume that along the length d of the region of the sawtooth surface an integral number D of periods fits in (we will consider D to be even for precision). Then, substituting (14) into (1) and performing the integration, we will obtain for the case of vertical polarization, after algebraic manipulations:

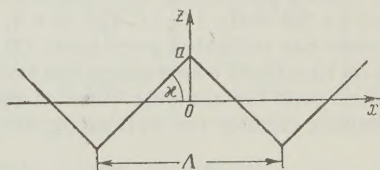


Figure 1

$$I = \frac{-j\Lambda}{2\pi \cos x} \frac{\sin \pi\beta D}{\sin \pi\beta} \left\{ \frac{\cos(\tau - \kappa) [p - \cos(\alpha - \kappa)]}{[p + \cos(\tau - \kappa)] \left(\beta - \frac{2\gamma}{\pi}\right)} (e^{-j\gamma} - e^{j\gamma} e^{-j\pi\beta}) + \right. \\ \left. + \frac{\cos(\tau + \kappa) [p - \cos(\alpha + \kappa)]}{[p + \cos(\tau + \kappa)] \left(\beta + \frac{2\gamma}{\pi}\right)} (e^{j\gamma} e^{j\pi\beta} - e^{-j\gamma}) \right\}. \quad (15)$$

The amplitudes of the scattered waves at the maxima of the lobes $I_\beta = N = I_N$ ($N = 0, \pm 1, \pm 2 \dots$) will be equal to

$$I_N = \frac{lD\Lambda(-1)^{N(D-1)}i^N}{\pi \cos \kappa} \sin\left(\gamma + \frac{N\pi}{2}\right) \times \\ \times \left\{ \frac{\cos(\tau + \kappa) [p - \cos(\alpha + \kappa)]}{[p + \cos(\tau + \kappa)] \left(N + \frac{2\gamma}{\pi}\right)} - \frac{\cos(\tau - \kappa) [p - \cos(\alpha - \kappa)]}{[p + \cos(\tau - \kappa)] \left(N - \frac{2\gamma}{\pi}\right)} \right\}. \quad (16)$$

Similarly, for the case of a horizontally polarized wave we will obtain

$$I = \frac{-j\Lambda}{2\pi \cos \kappa} \frac{\sin \pi\beta D}{\sin \pi\beta} \left\{ \frac{\cos(\tau - \kappa) [1 - p \cos(\alpha - \kappa)]}{[1 + p \cos(\tau - \kappa)] \left(\beta - \frac{2\gamma}{\pi}\right)} (e^{-j\gamma} - e^{j\gamma} e^{-j\pi\beta}) + \right. \\ \left. + \frac{\cos(\tau + \kappa) [1 - p \cos(\alpha + \kappa)]}{[1 + p \cos(\tau + \kappa)] \left(\beta + \frac{2\gamma}{\pi}\right)} (e^{j\gamma} e^{j\pi\beta} - e^{-j\gamma}) \right\}. \quad (17)$$

When $\beta = N$ (N is an integer)

$$I_N = \frac{lD\Lambda(-1)^{N(D-1)}i^N}{\pi \cos \kappa} \sin\left(\gamma + \frac{N\pi}{2}\right) \times \\ \times \left\{ \frac{\cos(\tau + \kappa) [1 - p \cos(\alpha + \kappa)]}{[1 + p \cos(\tau + \kappa)] \left(N + \frac{2\gamma}{\pi}\right)} - \frac{\cos(\tau - \kappa) [1 - p \cos(\alpha - \kappa)]}{[1 + p \cos(\tau - \kappa)] \left(N - \frac{2\gamma}{\pi}\right)} \right\}. \quad (18)$$

Substituting into (16) and (18) $p = 0$, we will obtain the formula for the amplitude of the wave at the maximum of the n -th lobe, scattered by an ideally conducting surface,

$$I_N = \pm \frac{lD\Lambda(-1)^{N(D-1)}i^{Nka}}{\left[\left(\frac{N\pi}{2}\right)^2 - \gamma^2\right]} [1 + \cos(\tau - \alpha)] \sin\left(\frac{N\pi}{2} + \gamma\right) \quad (19)$$

(the upper sign is used in the case of vertical polarization, the lower sign in the case of horizontal polarization). A formula, which differs from (19) by only a constant factor, was given by Brekhovskikh in his earlier work [1].

4. RESULTS OF THE CALCULATIONS

Let us examine the sample calculation for a sawtooth surface, which was performed for the case when $\tau = 0$ and the parameters of the surface were characterized by the following values $\Lambda/a = 10$, $\Lambda/\lambda = 3.75$, $p = 0.2 + j 0.05$. The absolute values of the amplitudes of the scattering lobes $|I_N|$ obtained by calculations are given in Table 1.² In the same table, values of $|I_N|/\sigma = \infty$ are calculated for ideally conducting surfaces for the same values of the parameters a and Λ are included, as well as the ratio $|I_N|/|I_N|_{\sigma = \infty}$.

As the author has indicated previously [3], when the conditions to the utilization of the method based on Kirchhoff's approximation are fulfilled, one may expect that the indicated expressions will be near the absolute value of the corresponding coefficient of reflection from a flat semiconducting surface (as well as p), the value of which is determined by the formulas

$$r_{\parallel} \approx \frac{\cos \theta - p}{\cos \theta + p} \quad (\text{vertical polarization}) \quad (20)$$

²In the performance of all calculations, factors connected with the dimensions of the scattering surface were omitted.

$$r_{\perp} \simeq \frac{p \cos \theta - 1}{p \cos \theta + 1} \quad (\text{horizontal polarization}) \quad (21)$$

From the formulas (20) and (21) (which are written for the case when $|\mu^* \epsilon^*| \gg 1$) values of the modulus of the coefficient of reflection from a flat surface with the parameter $p = 0.2 + j 0.05$ were calculated; in addition, in these formulas θ was understood as the angle between vectors $\vec{n}$ and $\vec{k}_0$, which corresponded to the assumption that the direction of propagation of the scattered wave coincides with the direction of the mirror reflection from certain portions of a rough surface.

As can be seen from Figure 2, in this case $\theta = \frac{1}{2} |\tau - \alpha_N|$, where α_N is the scattering angle, corresponding to the maximum of the N-th lobe.

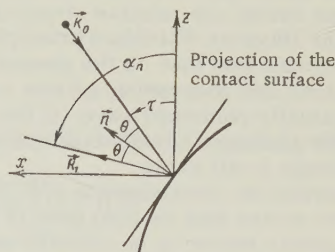


Figure 2

Table 1

	Vector $\vec{E}$ of the incident wave is perpendicular to the surface				Vector $\vec{E}$ of the incident wave is parallel to the surface			
	Order of the Scattering Spectrum							
	0	1	2	3	0	1	2	3
$ I_N $	0.137	0.0130	0.291	0.247	0.146	0.0138	0.310	0.263
$ I_N _{\sigma=\infty}$	0.212	0.0201	0.450	0.382	0.212	0.0201	0.450	0.382
$ I_N / I_N _{\sigma=\infty}$	0.646	0.646	0.646	0.646	0.688	0.688	0.688	0.688
Results of calculation of $ r $ from formulas (20) and (21) when $\theta = \frac{1}{2}$								
$ \tau - \alpha_N $	0.668	0.665	0.656	0.635	0.668	0.670	0.678	0.697

Table 2

Λ/λ	1.875	1.250	0.9375	0.750
$ I_0 $	0.321	0.500	0.576	0.615
$ I_0 _{\sigma=\infty}$	0.465	0.726	0.837	0.893
$ I_0 / I_0 _{\sigma=\infty}$	0.690	0.689	0.688	0.688
Results of calculation of $ r $ from formula (20) when $\theta = 0$	0.668	0.668	0.668	0.668

The results of the calculations shown in Table 1 show that the ratio $|I_N|/|I_N|_{\sigma=\infty}$ differs little from the modulus of the corresponding coefficient of reflection.

This conclusion is also confirmed by the calculations performed for the double sinusoidal surface, which were done according to formula (9) for the case $\tau = \alpha = 0$ and for the following surface parameters: $\Lambda = \Lambda'$, $\Lambda/a = 10$, $p = 0.2 + j 0.05$ (see Table 2).

CONCLUSION

The approximate solution to the problem of the scattering of electromagnetic waves by a double sinusoidal surface with finite conductance and the calculations performed on this surface reveal the relative simplicity and effectiveness of the method based on utilization of the Huygens-Kirchhoff principle and approximations from geometrical optics. It is also demonstrated that in the general case of a periodically rough surface, undulating in two directions and possessing a finite conductance, the scattered field in the far zone will be an elliptically polarized wave, if the incident wave is linearly polarized.

For the analogous ideally conducting surface, the polarization of the scattered wave will not change in all cases.

The method of determination of Kirchhoff's integral utilized in the work with the aid of the Fourier series may be also used in the solution of other problems on the scattering of electromagnetic waves by bi-periodic surfaces (whose conductance is finite) with unevennesses of a complex form. In this way, for instance, one may obtain the solution to a double trochoidal surface with finite conductance.

The method, proposed for the determination of Kirchhoff's integral in the case of a sawtooth surface, may be utilized for the determination of an analogous three-dimensional problem on the scattering of electromagnetic waves by a surface with pyramidlike roughnesses.

The possibility of using formulas (20), (21), which is indicated in the work, for the determination of the ratio $|I_N|/|I_N|_{\sigma=\infty}$ results in a simple method of determining the amplitude of waves scattered by a periodically rough surface with finite conductance, on the basis of the relation found for the ideally conducting surface which is analogous in form.

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UTILIZATION OF A TWO-ELEMENT INTERFEROMETER FOR THE INVESTIGATION OF FIELD FLUCTUATIONS

G.A. Karpeyev

A theoretical estimate of fluctuations at the output of a two-element interferometer, loaded by a square-law detector is given. The dependence of the character of the fluctuation of the output signal on the space correlation properties of amplitude-phase field fluctuations, as well as its regular characteristics are investigated.

1. DERIVATION OF GENERAL EXPRESSIONS FOR THE MATHEMATICAL EXPECTATION OF THE OUTPUT VOLTAGE FROM A SQUARE-LAW DETECTOR

Let there be a field

$$\vec{E}(P, t) = \vec{E}'(P, t) e^{i\varphi'(P, t)},$$

at every point P in a certain volume of space V.

The voltage at point C of the feeder system of the interferometer (Figure 1) will be equal to

$$\begin{aligned}\vec{E}_C(\vec{r}, t) &= G_1(t) \vec{E}(P_1, t) + G_2(t) \vec{E}(P_2, t) \\ &= E(P_1, t) e^{i\varphi(P_1, t)} + E(P_2, t) e^{i\varphi(P_2, t)}.\end{aligned}$$

Here $G_1(t)$ and $G_2(t)$ are the gains of the receiving elements, which are functions of time and which depend on the character of transient fluctuations of the phase of the wave at the opening of the receiving elements; $\varphi(P, t) = \tilde{\varphi}(P, t) + \varphi_r$, where $\tilde{\varphi}(P, t)$ is a certain average value of the phase of the field at the opening of the receiving elements; φ_r is the regular shift of the phases during transmission of the signal from point P to point C of the feeder system. The dimensions of the receiving elements will be considered from now on to be sufficiently small in comparison with the separation between the peaks of the correlation function of the amplitude-phase field fluctuations. Let us investigate the amplitude

$$U(\vec{r}, t) = \alpha \{ \vec{E}_C(\vec{r}, t) \vec{E}_C^*(\vec{r}, t) \} = \alpha \{ \beta^2(\vec{r}, t) + \gamma^2(\vec{r}, t) [e^{i\Phi(\vec{r}, t)} + e^{-i\Phi(\vec{r}, t)}] \} \quad (1)$$

of the output voltage of a square-law detector connected at point C of the feeder system. In order to simplify the notation, we have introduced the following

$$\beta^2(\vec{r}, t) = E^2(P_1, t) + E^2(P_2, t),$$

$$\gamma^2(\vec{r}, t) = E(P_1, t) E(P_2, t),$$

$$\Phi(\vec{r}, t) = \varphi(P_1, t) - \varphi(P_2, t);$$

the radius-vector $\vec{r}$ is equal in magnitude to the distance between points P_1 and P_2 and is directed from P_1 to P_2 .

If we consider that $E(P, t)$ and $\varphi(P, t)$ in the given space V are random functions of space and time, such that

$$E(P, t) = E_0(P) + E_1(P, t), \quad \varphi(P, t) = \varphi_0(P) + \varphi_1(P, t),$$

where $E_0(P) = \overline{E(P, t)}$; $\varphi_0(P) = \overline{\varphi(P, t)}$ (the line on top indicates statistical average); $E_1(P, t)$ and $\varphi_1(P, t)$ are the unknown random functions, stationary in time, we will then obtain

$$U_0(\vec{r}) = \overline{U(\vec{r}, t)} = \alpha \{ \beta^2(\vec{r}) + \gamma^2(\vec{r}) [e^{i\Phi(\vec{r}, t)} + e^{-i\Phi(\vec{r}, t)}] \}. \quad (2)$$

Here

$$\beta^2(\vec{r}) = \overline{\beta^2(\vec{r}, t)}; \quad \gamma^2(\vec{r}) = \overline{\gamma^2(\vec{r}, t)}.$$

It is shown [1] that if $f(X)$ is the distribution of the probability of a random value x, its characteristic function is then determined from the relation

$$g(\xi) = \int_{-\infty}^{\infty} e^{i\xi X} f(X) dX \quad (3)$$

and inversely

$$f(X) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-i\xi X} g(\xi) d\xi. \quad (4)$$

But

$$\overrightarrow{e^{i\Phi(r, t)}} = \int_{-\infty}^{\infty} e^{i\Phi} f(\Phi, \vec{r}) d\Phi$$

and will take the form, in accordance with (4),

$$\overrightarrow{e^{i\Phi(r, t)}} = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{i\Phi} \int_{-\infty}^{\infty} e^{-i\xi\Phi} g_{\Phi}(\xi, \vec{r}) d\xi d\Phi = \int_{-\infty}^{\infty} g_{\Phi}(\xi, \vec{r}) \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{-i(\xi-1)\Phi} d\Phi d\xi.$$

Since [1]

$$\frac{1}{2\pi} \int_{-\infty}^{\infty} e^{iX\Phi} d\Phi = \delta(X) = \begin{cases} 0 & \text{when } X \neq 0, \\ \infty & \text{when } X = 0, \end{cases}$$

then

$$\overrightarrow{e^{i\Phi(r, t)}} = \int_{-\infty}^{\infty} g_{\Phi}(\xi, \vec{r}) \delta(\xi - 1) d\xi = g_{\Phi}(1, \vec{r}).$$

Similarly

$$\overrightarrow{e^{-i\Phi(r, t)}} = \int_{-\infty}^{\infty} g_{\Phi}(\xi, \vec{r}) \delta(\xi + 1) d\xi = g_{\Phi}(-1, \vec{r}) = g_{\Phi}^*(1, \vec{r}),$$

where $g_{\Phi}^*(1, \vec{r})$ is the complex conjugate of $g_{\Phi}(1, \vec{r})$. In this way, the average value of the output signal from the square-law detector will be in the form

$$U_0(\vec{r}) = \alpha \{ \beta^2(\vec{r}) + \gamma^2(\vec{r}) [g_{\Phi}(1, \vec{r}) + g_{\Phi}^*(1, \vec{r})] \}. \quad (5)$$

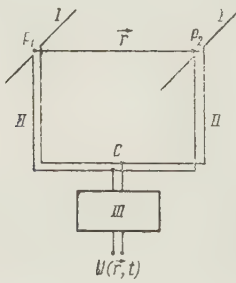


Figure 1. Two-element interferometer I - receiving elements; II - feeder system; III - square-law detector.

The characteristic functions $g_{\Phi}(1, \vec{r})$ and $g_{\Phi}^*(1, \vec{r})$ may be expressed in terms of the characteristic functions of the distribution $f(\varphi_1, \varphi_2)$ of a two-dimensional random vector $[\varphi(P_1, t), \varphi(P_2, t)]$. Indeed

$$g_{\Phi}(\xi, \vec{r}) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{i\xi\varphi_1} e^{-i\xi\varphi_2} f(\varphi_1, \varphi_2, \vec{r}) d\varphi_1 d\varphi_2 =$$

$$= \frac{1}{(2\pi)^2} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} g_{\Phi}(\xi_1, \xi_2, \vec{r}) d\xi_1 d\xi_2 \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-i(\xi_1, \xi_2) \cdot (z_1, z_2)} d\eta_1 d\eta_2 = \\ = g_{\Phi}(\xi_1, -\xi_2, \vec{r}).$$

Similarly

$$g_{\Phi}^*(\xi, \vec{r}) = g_{\Phi}(-\xi, \xi, \vec{r}).$$

The substitution of these relations into (5) results in

$$U_0(\vec{r}) = \alpha \{ \beta^2(\vec{r}) + \gamma^2(\vec{r}) [g_{\Phi}(1, -1, \vec{r}) + g_{\Phi}(-1, 1, \vec{r})] \}. \quad (6)$$

Since from the relation

$$\varphi(P, t) = \varphi_0(P) + \varphi_1(P, t) \text{ and } \overline{\varphi_1(P, t)} = 0,$$

then, using the known property of the characteristic functions [1], we will obtain

$$g_{\Phi}(\xi, \vec{r}) = e^{i\Phi_0(\vec{r})} g_{\Phi_1}(\xi, \vec{r}),$$

which after substitution into (5) and (6) gives

$$U_0(\vec{r}) = \alpha \{ \beta^2(\vec{r}) + \gamma^2(\vec{r}) [e^{i\Phi_0(\vec{r})} g_{\Phi_1}(1, \vec{r}) + e^{-i\Phi_0(\vec{r})} g_{\Phi_1}^*(1, \vec{r})] \} \quad (7)$$

or

$$U_0(\vec{r}) = \alpha \{ \beta^2(\vec{r}) + \gamma^2(\vec{r}) [e^{i\Phi_0(\vec{r})} g_{\Phi_1}(1, -1, \vec{r}) + e^{-i\Phi_0(\vec{r})} g_{\Phi_1}(-1, 1, \vec{r})] \}, \quad (8)$$

where

$$\Phi_0(\vec{r}) = \overline{\Phi(\vec{r}, t)} = \varphi_0(P_1) - \varphi_0(P_2).$$

Thus, under the normal law of the distribution $\varphi(P, t)$

$$g_{\Phi}(\xi, \vec{r}) = e^{i\Phi_0(\vec{r})} e^{-\frac{\sigma_{\Phi}^2(\vec{r})}{2} \xi^2}, \\ g_{\Phi_1}(\xi_1, \xi_2, \vec{r}) = \exp \left\{ -\frac{1}{2} [\sigma_{\Phi}^2(P_1) \xi_1^2 + 2\sigma_{\Phi}(P_1) \sigma_{\Phi}(P_2) \rho_{\Phi}(\vec{r}) \xi_1 \xi_2 + \right. \\ \left. + \sigma_{\Phi}^2(P_2) \xi_2^2] \right\}. \quad (9)$$

where

$$\sigma_{\Phi}^2(\vec{r}) = \sigma_{\Phi}^2(P_1) - 2\sigma_{\Phi}(P_1) \sigma_{\Phi}(P_2) \rho_{\Phi}(\vec{r}) + \sigma_{\Phi}^2(P_2);$$

$\sigma_{\Phi}^2(P)$ is the dispersion of the fluctuations of the phase of field at point P; $\rho_{\Phi}(\vec{r})$ is the space coefficient of the correlation of the phase fluctuations.

In this manner, for a normal distribution law the expression for $U_0(\vec{r})$ has the form

$$U_0(\vec{r}) = \alpha \{ \beta^2(\vec{r}) + 2\gamma^2(\vec{r}) \cos \Phi_0(\vec{r}) e^{-\frac{\sigma_{\Phi}^2(\vec{r})}{2}} \}. \quad (10)$$

in accordance with (7) - (9).

2. INVESTIGATION OF THE DEPENDENCE OF $U_0(\vec{r})$ ON $\vec{r}$

Without determining the mechanism by which the field fluctuations, which may be described by certain relations at the source of the field or in space, arise, let us perform a more detailed analysis of the expressions obtained above.

Even in the simplest case, when fluctuations of the amplitude and of the phase of the field are statistically independent, and when phase fluctuations obey the normal law of probability

distribution, $U_0(\vec{r})$, as can be seen from (10), is a sufficiently complicated function of space and does not only depend on the distance between receiving elements, but also on their location in space.

In order to clarify the character of the dependence of $U_0(\vec{r})$ on $\vec{r}$, let us examine several specific cases which may be of practical interest.

1. $\beta^2(\vec{r}) = \beta_0^2$

This condition is realized rather easily, if

$$E_0^2(P_1) = E_0^2(P_2) = E_0^2, \quad \sigma_F^2(P_1) = \sigma_E^2(P_2) = \sigma_E^2, \\ \text{where } \sigma_E^2(P) = \overline{E_1^2(P, t)}. \quad \text{here } \beta_0^2 = 2[E_0^2 + \sigma_E^2] \text{ so that we will obtain } U_0(\vec{r}) \text{ from for} \quad (10)$$

$$U_0(\vec{r}) = \alpha \left[\beta_0^2 + 2\gamma^2(\vec{r}) \cos \Phi_0(\vec{r}) e^{-\frac{\sigma_{\Phi}^2(\vec{r})}{2}} \right], \quad (11)$$

which, after the substitution $\gamma^2(\vec{r}) = E_0^2 + \sigma_E^2 \rho_E(\vec{r})$ and the assumption that $\sigma_{\Phi}^2(P_1) = \sigma_{\Phi}^2(P_2) = \sigma_{\Phi}^2$, will take on the form

$$U_0(\vec{r}) = \alpha \left\{ \beta_0^2 + 2[E_0^2 + \sigma_E^2 \rho_E(\vec{r})] \cos \Phi_0(\vec{r}) e^{-\sigma_{\Phi}^2 [1 - \rho_{\Phi}(\vec{r})]} \right\}. \quad (12)$$

It is seen from (12) that $U_0(\vec{r})$ depends on the statistical characteristics of amplitude and phase fluctuations of the field (dispersions and space coefficients of the correlation $\rho_E(\vec{r})$ and $\rho_{\Phi}(\vec{r})$, as well as on its regular characteristics, such as the average value of the amplitude of the field E_0 and the average phase difference $\Phi_0(\vec{r})$.

Let us assume that $\sigma_{\Phi}^2(\vec{r}) = 0$, which either corresponds to an absence of phase fluctuations ($\sigma_{\Phi}^2 = 0$), or else to the case $\rho_{\Phi}(\vec{r}) \equiv 1$ in the given part of the volume.

In this case the average output signal level exhibits regular space variations, in accordance with the regular phase difference $\Phi_0(\vec{r})$, and depends on the average power of the field amplitude fluctuations and on its space correlation properties:

$$U_0(\vec{r}) = \alpha \{ \beta_0^2 + 2[E_0^2 + \sigma_E^2 \rho_E(\vec{r})] \cos \Phi_0(\vec{r}) \}.$$

Thus, on the surface S such that $\Phi_0(\vec{r})|_S = (2m+1)\pi$ ($m = 0, 1, 2, 3, \dots$)

$$U_0(\vec{r}) = \alpha \{ \beta_0^2 - 2[E_0^2 + \sigma_E^2 \rho_E(\vec{r})] \} = 2\alpha\sigma_E^2 [1 - \rho_E(\vec{r})]$$

and varies from

$$\text{to } U_0(\vec{r})_{\min} = 0 \quad \text{when } \vec{r} = 0$$

$$\text{when } U_0(\vec{r})_{\max} = 2\alpha\sigma_E^2 [1 - \rho_E(\infty)] = 2\alpha\sigma_E^2$$

in accordance with the character of the variation in $\rho_E(\vec{r})$ on S .

On the other hand, when $\Phi_0(\vec{r})|_S = 2m\pi$, $U_0(\vec{r})$ varies from

$$U_0(\vec{r})_{\max} = 2\alpha \{ 2E_0^2 + \sigma_E^2 [1 + \rho_E(\vec{r})] \} = 4\alpha [E_0^2 + \sigma_E^2]$$

when $\vec{r} = 0$ to

$$U_0(\vec{r})_{\min} = 2\alpha \{ 2E_0^2 + \sigma_E^2 [1 + \rho_E(\infty)] \} = 2\alpha \{ 2E_0^2 + \sigma_E^2 \}$$

when $\lim_{|\vec{r}| \rightarrow \infty} \rho_E(\vec{r}) = 0$.

$$|\vec{r}| \rightarrow \infty$$

When $\Phi_0(\vec{r})|_S = (2m+1)\frac{\pi}{2}$ $U_0(\vec{r})$ does not vary in space and

$$U_0(\vec{r}) = \alpha \beta_0^2 = 2\alpha [E_0^2 + \sigma_E^2].$$

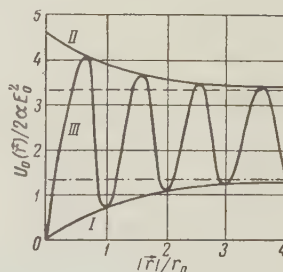
All intermediate cases

$$(2m-1)\pi \leq \Phi_0(\vec{r}) \leq (2m+1)\pi$$

will lie between the bordering curves (Figure 2) which correspond to $\Phi_0(\vec{r}) = 2m\pi$ and $\Phi_0(\vec{r}) = (2m+1)\pi$.

Finally, along the curve L, on which $\Phi_0(\vec{r}) = \Phi(L)$ is the point function of this curve, the $U_0(\vec{r})$ level will oscillate, and will have a form such as that depicted in Figure 2, where the distance $|\vec{r}| = |r(P_1, P_2)|$ is taken as the parameter of the curve L, and the shift difference of the phases in the feeder system is set equal to zero.

Figure 2. Graph of the dependence of $U_0(\vec{r})$ on $\vec{r}$:
I - when $\Phi_0(\vec{r}) = (2m+1)\pi$; II - when $\Phi_0(\vec{r}) = 2m\pi$;
III - when $\Phi_0(\vec{r}) = \Phi(L)$; dots - dashes - $y = \sigma_E^2/E_0^2$;
dashed line - $y = \frac{\sigma_E^2}{E_0^2} + 2$, $\rho_E(r_0) = 0.5$



$$2. \sigma_E^2(\vec{r}) \gg 1.$$

In this case, the second term in (10) may be neglected in comparison with the first term, and

$$U_0(\vec{r}) \simeq \alpha \beta^2(\vec{r}),$$

from which it is seen that $U_0(\vec{r})$ does not depend on the regular phase difference and on the space correlation properties of field amplitude and phase fluctuations.

This same result can be obtained from (5) under the assumption of a symmetrical distribution curve of fluctuations of the phase difference.

$$\int \langle \Phi \rangle d\Phi = \frac{d\langle \Phi \rangle}{2\pi}.$$

In this way, the condition $\sigma_E^2(\vec{r}) \gg 1$ in the normal distribution curve is equivalent to the symmetrical distribution of phase differences of the investigated field in the interval $(0, 2\pi)$.

3. We have investigated above the dependence of $U_0(\vec{r})$ on $\vec{r}$, by making certain assumptions as to the character of the phase fluctuations of the wave. Let us now assume that the field fluctuations are such that

$$\sigma_E^2/E_0^2 \ll 1.$$

By neglecting the terms of the order of σ_E^2/E_0^2 in comparison with unity in (10), we will obtain

$$U_0(\vec{r}) \simeq 2\alpha E_0^2 \left\{ 1 + \cos \Phi_0(\vec{r}) e^{-\frac{\sigma_E^2(\vec{r})}{2}} \right\}.$$

The analysis of the dependence of this function on $\vec{r}$ is similar to the one given above and reveals that when $\Phi_0(\vec{r}) = 2m\pi$ $U_0(\vec{r})$ varies from

$$U_0(\vec{r})_{\max} = 4\alpha E_0^2$$

when $\vec{r} = 0$ to

$$U_0(\vec{r})_{\min} = 2\alpha E_0^2 \left[1 + e^{-\frac{\sigma_{\Phi}^2(\infty)}{2}} \right] = 2\alpha E_0^2 \left[1 + e^{-\frac{\sigma_{\Phi}^2}{2}} \right]$$

when $\lim_{|\vec{r}| \rightarrow \infty} \rho_{\Phi}(\vec{r}) = 0$.

When $\Phi_0(\vec{r}) = (2m+1)\pi$ $U_0(\vec{r})$ is of the form

$$U_0(\vec{r}) = 2\alpha E_0^2 \left[1 - e^{-\frac{\sigma_{\Phi}^2(\vec{r})}{2}} \right]$$

and varies from

$$U_0(\vec{r})_{\min} = 0$$

when $\vec{r} = 0$ to

$$U_0(\vec{r})_{\max} = 2\alpha E_0^2 \left[1 - e^{-\frac{\sigma_{\Phi}^2}{2}} \right]$$

when $|\vec{r}| \rightarrow \infty$

Upon movement along the space curve L - such that $\Phi_0(\vec{r}) = \Phi(L)$, $U_0(\vec{r})$ will exhibit oscillations, just as in Figure 2, but will have an envelope determined by the character of the space correlation properties of the phase fluctuations in the investigated process.

In the general case, when in (5) [or (10)] there exists the influence of amplitude as well as of phase fluctuations of the fields, $U_0(\vec{r})$ will exhibit space oscillations dependent on the space characteristics of the amplitude-phase field fluctuations, as well as on the regular phase difference.

The space periodicity of $U_0(\vec{r})$ will be determined by the character of the variation of $\cos \Phi_0(\vec{r})$ along that curve L which is chosen as the basis of the receiving elements, and is determined not only from the geometry of this curve, but also from the space distribution of the phase in the incident wave.

Thus, if the investigated wave process is of a plane (on the average) wave with a wave vector $\vec{K} = \vec{K}_0$ then

$$\Phi_0(\vec{r}) = \vec{K}_0 \vec{r}$$

and the contours, for which $\Phi_0(\vec{r}) = \Phi_0$ lie on the planes $\vec{K}_0 \vec{r} = \Phi_0$ perpendicular to the wave vector $\vec{K}_0$.

The greatest phase gradient will be observed along the straight lines $\vec{K}_0 \vec{r} = Kr$, parallel to the wave vector of the incident wave.

When $\cos(\vec{K}_0 \vec{r}) = \text{const}$, $\Phi_0(\vec{r}) = \frac{2\pi}{\lambda} r \cos(\vec{K}_0 \vec{r})$ and the space period of variations of the average output signal level will be determined from

$$\lambda_{\text{str}} = \lambda / \cos(\vec{K}_0 \vec{r})$$

along any straight line which lies on the conic surface with its tip at point P_1 , and with its axis perpendicular to the wave front.

$$4. \sigma_{\Phi}^2(\vec{r}) \ll 1, \quad \sigma_E^2/E_0^2 \ll 1.$$

For the relatively small amplitude-phase fluctuations of the field, we will obtain from (10)

$$U_0(\vec{r}) \simeq \alpha \left\{ \beta_0^2 + 2 \left[\gamma^2(\vec{r}) - \frac{E_0^2 \sigma_{\Phi}^2(\vec{r})}{2} \right] \cos \Phi_0(\vec{r}) \right\}.$$

if we form a series from $e^{-\frac{\sigma_{\Phi}^2(\vec{r})}{2}}$ and if we neglect terms of lower order of magnitude.

Let us further assume that $\Phi_0(\vec{r}) = m\pi + \Phi_1(\vec{r})$, where $\Phi_1(\vec{r}) \ll 1$, and that one may state with a sufficient degree of accuracy that

$$\cos \Phi_0(\vec{r}) \simeq (-1)^m \left[1 - \frac{1}{2} \Phi_1^2(\vec{r}) \right].$$

Substitution of this relation into (12) results in

$$U_0(\vec{r}) \simeq \alpha E_0^2 \left\{ [1 + (-1)^m]^2 + (-1)^{m+1} \sigma_{\Phi}^2(\vec{r}) + (-1)^{m+1} \Phi_1^2(\vec{r}) + \right. \\ \left. + \frac{2\sigma_E^2}{E_0^2} [1 + (-1)^m \rho_E(\vec{r})] \right\}. \quad (13)$$

As a specific instance, if $\Phi_1(\vec{r})$ is so small that its square may be neglected in the last equation, then

$$U_0(\vec{r}) \simeq \alpha E_0^2 \left\{ [1 + (-1)^m]^2 + (-1)^{m+1} \sigma_{\Phi}^2(\vec{r}) + \frac{2\sigma_E^2}{E_0^2} [1 + (-1)^m \rho_E(\vec{r})] \right\}.$$

Thus, when $m = 1$ (or for any odd number)

$$U_0(\vec{r}) \simeq 2\alpha E_0^2 \left\{ \frac{\sigma_E^2}{E_0^2} [1 - \rho_E(\vec{r})] + \frac{\sigma_{\Phi}^2(\vec{r})}{2} \right\} = \\ = 2\alpha E_0^2 \left\{ \frac{\sigma_E^2}{E_0^2} [1 - \rho_E(\vec{r})] + \sigma_{\Phi}^2 [1 - \rho_{\Phi}(\vec{r})] \right\},$$

which corresponds to the result obtained previously [2].

In this way, the utilization of an interferometer results in the possibility of investigation of the statistical laws of amplitude-phase fluctuations of wave fields. In the case of a relatively small fluctuations, as follows from (13), the utilization of the interferometer gives a sufficiently simple method of investigating the space correlation properties of amplitude-phase field fluctuations. Especially rewarding in terms of results is the application of the interferometer to the investigation of relatively small field fluctuations in the study of the statistical distributions of microwaves in a turbulent medium [2].

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ON THE THEORY OF TRAVELING WAVE OSCILLATORS WITH WEAK FEEDBACK

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The theory of traveling-wave oscillators is given from the standpoint of kinematic approximations and an analysis of their operation is included. A conclusion is offered concerning the prospect of increasing the electronic tuning precision of oscillator systems with normal dispersion.

1. INTRODUCTION. ELECTRONIC CONDUCTANCE.

The question of the conditions under which oscillations appear in traveling wave tubes is investigated in a number of articles [1 - 10]. However, the qualitative examination performed in these works does not permit us to clarify a number of peculiarities of traveling-wave oscillators. In this article an attempt is made to illuminate certain of the main conditions of operation of such oscillators in the case of weak feedback, when there is observed a significant growth of the amplitude of the wave in the direction of retardation. Let us avoid a detailed explanation of the mechanism which results in the formation of feedback in the tube, and consider instead that the feedback coefficient for the examined space harmonics is $k = E_{in}/E_{out} \ll 1$ and does not depend on the frequency of the oscillations near one of its proper frequencies, (E_{in} and E_{out} are the voltage amplitudes of a high-frequency field at the input and output of the delay system, at the point where a flow of electrons occurs).

Practically, such conditions are best realized in oscillators with external feedback; one may consider them to be fulfilled in oscillators with internal feedback only if the influence of the modulation of the electron flow on the reflected wave is negligibly small. In a reflective traveling-wave tube these conditions are not fulfilled.

The delay system, examined from the side of the output of energy at the load (the latter can be considered to be connected to the collector), will appear as a regular resonator, whose proper frequencies are placed rather close to each other.

Let us assume that steps are taken in the apparatus to ensure the separation of the proper frequencies. These steps may consist only in the introduction into the feedback loop of a special filter, or else in the utilization of systems with a normal dispersion [8]. Thus, we will not consider in the analysis of operation of the oscillator the possibilities of oscillations at neighboring frequencies and the skip effect on the waves that results.

It is known that under the condition of an electron flow in the delay system, three waves propagate. In the analysis one may neglect to consider the influences on the electron flow by the attenuated wave and by the wave with constant amplitude. This condition must not influence greatly the results of the calculations in our case since for small k the amplification of the third wave is so great that

$$\frac{1}{3} k e^{\gamma l} = 1, \quad (1)$$

where l is the length of the delay system; γ is the propagation constant; the current flow will be influenced by the growing wave to a considerably greater extent than by the other two waves. Here we will consider the reaction of the flow with only one definite space harmonic of the wave, determined single-valuedly by the magnitude of the phase velocity v_{Φ} .

Solving the problem of the bunching of electrons in the traveling wave, increasing exponentially, V. N. Sherchik [10] has found from the expression for the motion of the electrons

$$\frac{d^2 x}{dt^2} = \frac{e}{m} E_1 e^{\gamma x} \cos(\omega t - \beta x); \quad \beta = \frac{\omega}{v_{\Phi}} \quad (2)$$

(e and m are the charge and mass of the electron; v_Φ is the phase velocity of the wave) that the angle of flight of the electron is

$$\varphi = \varphi_0 - \frac{\mu e \frac{\gamma v_0 \varphi_0}{\omega}}{\rho \left(1 + \frac{\gamma^2}{\theta^2}\right)} \sin \left(\omega t - \frac{v_0}{v_\Phi} \varphi - \psi \right), \quad (3)$$

where

$$\begin{aligned} \operatorname{tg} \psi &= \frac{1 - \frac{\gamma^2}{\theta^2}}{2 \frac{\gamma}{\theta}}, \quad \theta = \frac{\omega}{v_0} \rho = \frac{\omega}{v_0} \left(1 - \frac{v_0}{v_\Phi}\right); \quad \mu = \frac{\varepsilon E_1}{m v_0 \omega \left(1 - \frac{v_0}{v_\Phi}\right)}; \\ \varphi &= \omega t - \omega \tau; \quad \varphi_0 = \frac{\omega x}{v_0}, \end{aligned} \quad (4)$$

and v_0 is the speed of the undisturbed electron; τ is the time of entry of the electron into the system. In the integration of expression (2) it was assumed that one may substitute $x \simeq v_0 (t - \tau)$ into the exponential, and when relation (3) was obtained all terms not containing the factor

$e^{\frac{\gamma v_0 \varphi_0}{\omega}} = e^{\gamma \kappa}$, were discarded. The latter approximation is only good in the case of oscillators with sufficiently weak feedback.

It is necessary for the calculation of the current $i = I_0 \left[1 - \frac{d\varphi}{d(\omega t)}\right]$ to solve Equation (3) for φ . Since (3) is in the form of Kepler's equation [11], the solution is of the form

$$\varphi = \varphi_0 + \frac{v_\Phi}{v_0} \sum_{n=1}^{\infty} \frac{2}{n} J_n(nX) \sin \left[n \left(\frac{v_0}{v_\Phi} \varphi_0 + \psi - \omega t \right) \right], \quad (5)$$

where

$$X = \frac{v_0}{v_\Phi} \frac{\mu e \frac{\gamma v_0 \varphi_0}{\omega}}{\rho \left(1 + \frac{\gamma^2}{\theta^2}\right)} = \frac{\varepsilon E_1 \omega}{m v_\Phi v_0^2 (\theta^2 + \gamma^2)} e^{\gamma \kappa} = D e^{\gamma \kappa}, \quad (6)$$

from which

$$i = I_0 \left\{ 1 + 2 \frac{v_\Phi}{v_0} \sum_{n=1}^{\infty} J_n(nX) \cos [n(\omega t - \beta x - \psi)] \right\}. \quad (7)$$

Considering that the power of the interaction of the electron flow with the field may be found from relation [10]

$$P = \frac{v_0}{2\omega} \int_0^{\varphi_0} i E^* d\varphi_0, \quad (8)$$

it is simple to find P [12]

$$P = \frac{E_1 v_\Phi I_0 e^{-j\psi}}{D \gamma v_0} \int_0^X J_1(X) dX = \frac{v_\Phi I_0 E_1}{D \gamma v_0} [1 - J_0(X)] e^{-j\psi}. \quad (9)$$

If the mutual interaction is examined from $x = 0$ to $x = l$, then expression (9) determines the full power delivered by the oscillator. Since from the energy output side the vibrating system of the oscillator may be near one of the proper frequencies generated by a regular resonator, and since the resonator at a certain cross section of the transmission line may be represented by parallel circuits, the vibrating section of the oscillator may be represented as the parallel combination of the elements L , C , G and G_L is determined from load losses, and G is determined from losses in the apparatus. Electron flow in this circuit will be represented by the admittance Y_e , related to P by the equation $2P = Y_e U^2$, where U is the amplitude of oscillations in the circuit. The value U is determined by the voltage amplitude of the field $E_1 e^{\gamma l}$, and their coupling may be found from the relation $3U = M E_1 e^{\gamma l}$, where the coefficient M is determined from the parameters of the output circuit and the delay system, the distance

of the electron flow from the system, and the number of the space harmonic; in each concrete case the coefficient M will have a fully defined value.

Here it is not difficult to obtain the relation for the electronic conductance in the form

$$Y_e = 2G_0 \frac{1 - J_0(X)}{X^2} e^{-j(\delta + \pi)} = G_e + jB_e, \quad (10)$$

where

$$G_0 = \frac{9e\omega I_0}{\gamma m M^2 v_0^3 (\theta^2 + \gamma^2)} = pI_0; \quad X = \frac{3e\omega U}{m M v_0 v_0^2 (\theta^2 + \gamma^2)} = rU;$$

$$\delta = \psi - \pi = \arctg \frac{\theta^2 - \gamma^2}{2\gamma\theta} - \pi.$$

The magnitude will be called from now on the bunching parameter.

2. ANALYSIS OF OPERATION OF OSCILLATOR

One may show [13] that the condition for the stability of stationary vibration in the oscillator is determined from the inequality

$$\frac{\partial}{\partial U} [G_e] < 0. \quad (11)$$

Using (10), this inequality may be transformed to

$$\frac{\partial}{\partial X} \left[\frac{1 - J_0(X)}{X^2} \cos \delta \right] = \frac{1}{X^3} \{ X J_1(X) - 2[1 - J_0(X)] \} \cos \delta < 0. \quad (12)$$

Solving the graphical relation $X J_1(X) = 2 - 2J_0(X)$, one may find that the oscillator is stable under the condition $\cos \delta > 0$ when $0 < X < 7.79$.

Examining the above-indicated equivalent circuit of the oscillator, one may obtain the expressions for the output power and frequency of generated oscillations:

$$P_L = \frac{G_L U^2}{2} = \frac{G_L X^2}{2r^2}; \quad \frac{X^2}{1 - J_0(X)} = \frac{2G_0 \cos \delta}{G + G_L}; \quad (13)$$

$$\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} \right) = -\frac{\gamma \delta}{Q_L} \approx 2 \frac{\Delta \omega}{\omega_0}; \quad \Delta \omega = \omega - \omega_0, \quad (14)$$

where $Q_L = \omega_0 C / (G + G_L)$ is the loaded quality factor of the oscillator.

The graph of the function $X^2 = f \left[\frac{X^2}{1 - J_0(X)} \right]$ is shown in Figure 1; it makes possible construction of the "oscillation zone" of the apparatus with the help of (13), i.e., using the relation $P_L = f(v_0)$. It follows from expressions (10), (13) and Figure 1 that the initial current of the oscillator is determined by the formula

$$I_{on} = \frac{2C\omega_0}{Q_L p \cos \delta} = -\frac{mCM^2(\theta^2 + \gamma^2)v_0^3}{9eQ_L\theta}. \quad (15)$$

The center of the oscillation zone, determined from the condition $\cos \delta = -2\gamma\theta/(\theta^2 + \gamma^2) = 1$, will become evident when $\theta = \gamma$ i.e., when

$$v_0 = \frac{v_\phi}{1 - \frac{\gamma}{\beta}}. \quad (16)$$

In this way, it is necessary for oscillation in the central zone that the velocity of electrons be greater than the wave velocity by the quantity

$$v_0 - v_\phi = \frac{v_\phi}{\frac{\beta}{\gamma} - 1}. \quad (17)$$

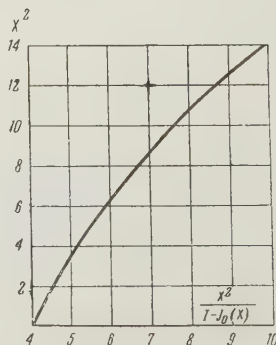


Figure 1

Let us analyze Equation (14) which determines the frequency of the generated oscillations. Taking advantage of Equations (4) and (10) formula (14) may be transformed into

$$\left(\frac{\omega}{\omega_0}\right)^2 = \frac{1 + \frac{\gamma}{2Q_L \theta_0}}{1 + \frac{\theta_0}{2Q_L \gamma}}; \quad \theta_0 = \frac{\omega_0}{v_0} \left(1 - \frac{v_0}{v_\Phi}\right), \quad (18)$$

from which it follows that

$$\frac{d\omega}{dv_0} = \left[\frac{4Q_L \omega \theta_0^2 \left(1 + \frac{\theta_0}{2Q_L \gamma}\right)^2 v_0^2}{\omega_0^2 \gamma \left(1 + \frac{\theta_0^2}{\gamma^2} + \frac{\theta_0}{Q_L \gamma}\right)} + \frac{v_0^2}{v_\Phi^2} \frac{\partial v_\Phi}{\partial \omega} \right]^{-1} \quad (19)$$

For the center of the oscillation zone this formula will be in the form

$$\left(\frac{d\omega}{dv_0}\right)_0 = \left[\frac{4Q_L \gamma v_0^2 \left(1 - \frac{1}{2Q_L}\right)^2}{\omega_0^2 \left(2 - \frac{1}{Q_L}\right)} + \frac{v_0^2}{v_\Phi^2} \left(\frac{\partial v_\Phi}{\partial \omega}\right)_0 \right]^{-1} = \frac{1}{B v_0^2}. \quad (20)$$

It is evident from Equation (20) that the oscillator in the central zone will have an infinite steepness of the electronic frequency tuning in the case of normal dispersion when $B = 0$, i.e., when

$$\left(\frac{\partial v_\Phi}{\partial \omega}\right)_0 = - \frac{4Q_L \gamma v_\Phi^2 \left(1 - \frac{1}{2Q_L}\right)^2}{\omega_0^2 \left(2 - \frac{1}{Q_L}\right)} \simeq - \frac{2Q_L \gamma v_\Phi^2}{\omega_0^2} = - \frac{Q_L \gamma \lambda^2}{2\pi^2} \left(\frac{v_\Phi}{c}\right)^2, \quad (21)$$

where γ and c are the wavelength and velocity of light in free space.

It follows from (20) that in the neighborhood of the central zone

$$\omega = \omega_0 + \frac{1 - \frac{1}{B}}{B v_\Phi} - \frac{1}{B v_0}. \quad (22)$$

It is evident from (22) that for a high steepness of the dispersion characteristic for normal dispersion, (when $B < 0$) the frequency decreases with a growth in velocity, and in the other cases (when $B > 0$) the frequency increases with increasing accelerating potential. It also follows from Equation (22) that the frequency must vary with changing accelerating voltage (U_0), according to an almost linear relation $\omega = f(U_0)$ under the condition of a small change in the frequency of the generated oscillations. Experiments, performed for systems not possessing a high steepness of the dispersion characteristics under normal dispersion [3, 4] have fully confirmed these conclusions.

It can be seen from Equations (10) and (15) that the frequency, generated on the border of the zone, is determined from the roots of the equation

$$\theta^2 - \frac{\theta}{N v_0} + \gamma^2 = 0; \quad N = \frac{M}{3} \sqrt{\frac{C m \omega_0}{I_0 e Q_L} \left(\frac{v_0}{v_\Phi} - 1\right)}. \quad (23)$$

If it is here considered that the frequency is connected with the velocity v_0 by Equation (22) then it is not difficult to obtain for the entire band of electronic frequency retuning of the oscillator the approximate formula

$$\Delta\omega_p = \frac{\sqrt{1 - 4N^2 v_0^2 \gamma^2}}{N \left| B\omega_0 v_\Phi + \frac{\gamma}{\beta_0} \right|}; \quad \beta_0 = \frac{\omega_0}{v_\Phi}, \quad (24)$$

where the magnitudes v_0 and v_Φ are taken as the ones which correspond to the central zone. It follows from (24) that the principal reason for the small value of $\Delta\omega_p$, usually obtained in practice, consists of the fact that the utilized delay systems have a large value of the magnitude B . Hence, if the oscillator is so constructed that condition (21) is satisfied, its band of electronic frequency retuning will be sufficiently large.

Making use of Equations (13), (10) and (22), one may show that the band of electronic frequency retuning, is determined by the following relation up to such points in the zone at which the power is decreased n times in comparison with the power in the central zone (where the bunching parameter attains its maximum value, equal to X_m):

$$\begin{aligned} \Delta\omega_n &= \frac{4G_0 Q_L \sqrt{n^2 [1 - J_0(X_m/\sqrt{n})]^2 - [1 - J_0(X_m)]^2}}{C \left| \frac{\omega_0^2}{\gamma} B - \frac{\beta_0^2}{\gamma} \left(\frac{\partial v_\Phi}{\partial \omega} \right)_0 + 1 \right| X_m^2} = \\ &= \frac{4G_0 Q_L \psi(X_m)}{C \left| \frac{\omega_0^2}{\gamma} B - \frac{\beta_0^2}{\gamma} \left(\frac{\partial v_\Phi}{\partial \omega} \right)_0 + 1 \right|}, \end{aligned} \quad (25)$$

where all the values of the parameters at the right side are taken as corresponding to the central zone.

From the condition $\partial\psi/\partial X_m = 0$ one may find values $X_m = X_{m0}$ for which the magnitude $\psi = \psi_m$ is maximum for the given n . It is not difficult to show that X_{m0} is obtained in this case from the graphical solution of the equation

$$\begin{aligned} n^2 \left[1 - J_0 \left(\frac{X_{m0}}{\sqrt{n}} \right) \right] \left\{ \frac{X_{m0}}{\sqrt{n}} J_1 \left(\frac{X_{m0}}{\sqrt{n}} \right) - 2 \left[1 - J_0 \left(\frac{X_{m0}}{\sqrt{n}} \right) \right] \right\} = \\ = [1 - J_0(X_{m0})] \{ X_{m0} J_1(X_{m0}) - 2 [1 - J_0(X_{m0})] \}. \end{aligned}$$

Graphs of the relations $X_{m0} = f(n)$ and $\psi_m = f(n)$ are given in Figure 2.

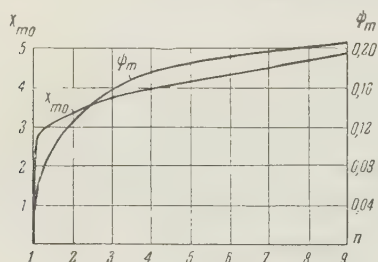


Figure 2

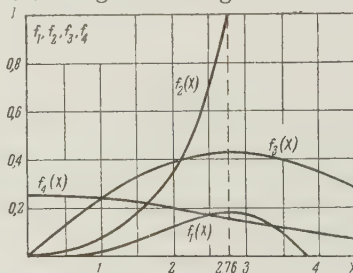


Figure 3

Making use of the equality $dP_L/dG_L = 0$, one may obtain in accordance with (13) the condition for optimum loading of the oscillator for the given X :

$$\frac{J_1(X)}{X} = \frac{G}{G_0 \cos \delta}; \quad \frac{1}{X} \left[2 \frac{1 - J_0(X)}{X} - J_1(X) \right] = \frac{G_L}{G_0 \cos \delta}. \quad (26)$$

On the basis of (13) one may obtain the relation for the efficiency of the oscillator in the form

$$\eta_L = \frac{G_L X^2}{2I_0 U_0 r^2}. \quad (27)$$

If we make use of Equations (26) and (10), then it is not difficult to obtain from (27) a formula which determines the maximum efficiency for the given X:

$$\eta_{Lm} = \frac{I_0 \cos^2 \delta}{2GU_0} \left(\frac{3v_\phi}{\gamma M v_0} \right)^2 \left\{ 2 \frac{J_1(X)}{X} [1 - J_0(X)] - J_1^2(X) \right\}. \quad (28)$$

The function $\left\{ 2 \frac{J_1(X)}{X} [1 - J_0(X)] - J_1^2(X) \right\} = f_1(X)$ is shown in Figure 3. It has a maximum equal to 0.179 at $X = 2.76$. Hence, an especially large value of η_{Lmm} , determined from

$$\eta_{Lmm} = 0.805 \frac{I_0}{GU_0} \left(\frac{v_\phi \cos \delta}{\gamma M v_0} \right)^2. \quad (29)$$

is observed at $X = 2.76$.

Graphs of the functions

$$2 \frac{1 - J_0(X)}{X J_1(X)} - 1 = f_2(X); \quad \frac{1 - J_0(X)}{X} = f_3(X); \quad \frac{1 - J_0(X)}{X^2} = f_4(X).$$

are also shown in Figure 3.

The function $f_2(X)$ determines the optimum relative loading of the oscillator for the given X, since it follows from (26) that under the optimum loading $f_2(X) = G_L/G = Q/Q_{out}$, where Q_{out} and Q are the outside and proper quality-factors of the resonant system of the oscillator. It follows from the graph of the function $f_2(X)$ that $G = G_L(f_2(X) = 1)$ when $x = 2.76$; in this way, the maximum efficiency corresponds to that case when the power dissipated in the oscillator is equal to the power brought to the load.

The function $f_3(X)$ represents the oscillating characteristic of the oscillator; it has a maximum equal to 0.423, also at $X = 2.76$.

The function $f_4(X)$ characterizes the change in the modulus of electronic conductance with a change in x .

Making use of the general relations of the theory of the one-circuit klystron [3], one may obtain a shortened relation for the formation of amplitude in the oscillator:

$$\frac{1}{U} \frac{dU}{dt} = \frac{\omega_0}{2Q_L} \left[2\sigma \frac{1 - J_0(X)}{X^2} - 1 \right], \quad (30)$$

where $\sigma = G_0 \cos \delta / (G_L + G)$. If one makes use of the approximation $\frac{1 - J_0(X)}{X^2} \simeq 0.25 \times \left[1 - \frac{X^2}{16} \right]$, then on the basis of (30) it is not difficult to obtain the law for the formation of vibrations in the oscillator:

$$U(t) = U_c \left[1 - \left(\frac{U_c^2}{U_T^2} - 1 \right) e^{-\frac{\omega_0}{Q_L} \left(\frac{\sigma}{2} - 1 \right) t} \right]^{-1/2}, \quad (31)$$

where U_c is the amplitude during normal operation, determined from (13); U_T is the initial jump in the amplitude arising from fluctuating phenomena. In a manner similar to (13), one may show that the moment of formation of vibrations in the oscillator will be determined by the relation

$$t_y = \frac{2Q_L}{\omega_0(\sigma - 2)} \left\{ \ln \left[Q_L \left(\frac{\sigma}{2} - 1 \right) \right] + \ln \left(\frac{U_c^2}{U_T^2} - 1 \right) \right\}. \quad (32)$$

The influence of loading on operation of the examined oscillator is analogous to the influence of loading on operation of reflective systems and magnetrons so that all these devices will have the same type of loading characteristics.

CONCLUSIONS

In discussions of the steepness of electronic frequency tuning [1, 2], the great possibilities of systems with anomalous dispersion were noted. These conclusions were made as a result of the fact that the authors of the works [1, 2], studying the phase conditions, actually were examining the possibility of wideband resonance in the vibrating system of the oscillator and completely ignored the influence of the reactance of the electron flow. However, simple

arguments show that if the reactive influence of the flow is taken into account, the system with normal dispersion is seen to possess the best properties for a high steepness of the electronic frequency retuning of the oscillator. In fact, it follows from Equation (17) that during operation of the oscillator at the resonance frequency of the system, the electrons must outrun the wave with a speed which is greater, the greater is the phase velocity. A violation of this condition results in a change in the frequency; in addition, in the case $B > 0$, as follows from Equation (22) and from experiments [3, 4], the frequency will increase with increase in v_0 .

The more condition (17) is violated, the greater the change in frequency; hence, under normal dispersion the frequency will be changed to a greater extent for a change in v_0 from the given value, which is readily apparent from Equation (17). The steepness of electronic frequency retuning is closely connected with the width of the oscillator band, but does not determine the latter single-valuedly. The second determining factor, just as in the other oscillators, is the bandwidth of the system and the beam current. The greater the ratio I_0/Q_L , the wider the band of generated oscillations.

Since in the utilization of systems with a normal dispersion a good separation of the proper frequencies is observed [8], such systems are apparently very useful for wide-band oscillators based on the traveling wave tube.

It must be noted that in the examination of the dependence of the phase velocity on frequency the influence of the bunch on the magnitude V_Φ was not considered. An approximate consideration of this effect gives for V_Φ of the growing wave the relation [10]

$$v_\Phi = \frac{v_{\Phi 0}}{1 + \frac{v_{\Phi 0}}{2v_0} \sqrt{\frac{I_0 R_c}{4U_0}}}, \quad (33)$$

where $v_{\Phi 0}$ corresponds to the cold system; R_c is the coupling resistance. The correction which occurs here results in a negligible change of formulas (19), (20) and (21).

The relations obtained in the present work are found to agree qualitatively with the given experiments and are analogous in character to the corresponding formulas of the theory on reflective systems [13].

It follows from the examination of the operation of oscillators based on a traveling wave tube that they may be included in the class of oscillators examined in the work [14], and hence one may use the conclusions obtained in [14] when investigating the resonance loading of such generators.

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GENERALIZATION OF IMPEDANCE CIRCULAR DIAGRAMS TO THE CASE OF MICROWAVE CHANNELS WITH NEGATIVE RESISTANCE

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A circular impedance chart is utilized for channels with lumped and distributed negative impedances. The coefficient of reflection becomes greater than unity in this case and the operating region of the impedances falls beyond the borders of the circle with a unit radius. Certain cases of the connection of negative impedances which may be solved by way of inversion with the usual circular chart are examined.

The development of amplifiers with distributed interaction (tubes with traveling waves) and of parametric amplifiers leads to the necessity of working with active SHF (superhigh frequency) channels conducting the growing waves. In what way can circular impedance charts be utilized for channels of this kind? It is known that the amplifying process (generation) of oscillations may be explained in any particular system, by making use of an understanding of the equivalent negative resistance R introduced into this system. If one were to examine the expression for the radius vectors r and r' which determine the loci of constant values of the active R/Z_0 and reactive X/Z_0 of the corresponding impedances of the circular chart in polar coordinates, then one would find that the region with a negative impedance is outside the circle with unit radius [1]. In fact, indicated expressions are of the form

$$r = \frac{1}{\frac{R}{Z_0} + 1} \quad \text{for} \quad \frac{R}{Z_0} < 0, \quad r > 1, \quad (1)$$

$$r' = \frac{Z_0}{X},$$

where Z_0 is the characteristic impedance of the channel.

The system of orthogonal circles corresponding to $\infty > R/Z_0 > -\infty$ is shown in Figure 1; the circle delineated by dashes represents the circular chart in the usual sense ($R > 0$).

Let us examine certain cases of the introduction of a negative resistance into the SHF line.

1. A NEGATIVE RESISTOR IS CONNECTED INTO A LOADED LINE WITH A REFLECTION COEFFICIENT Γ_L

An example of such a system (Figure 2) may be a line with a connected system which is underexcited. The system will operate as an amplifier. The signal to be amplified, E^+ is introduced from left to right, the amplified signal E^- in the simplest case is equally divided between two equal directed lines to the left and right. Depending on the coefficient of reflection Γ_L the signal which passes to the right either separates at the load, or else is fully or partly reflected to the oscillator. The coefficient of reflection along the Z axis of such a system may be written in the form

$$\Gamma_A = \frac{E^-}{E^+} = \frac{1}{2} g e^{-2j\beta z} (1 + \Gamma_L e^{2j\beta l}), \quad (2)$$

where z is the lengthwise coordinate, measured from the load to the generator;

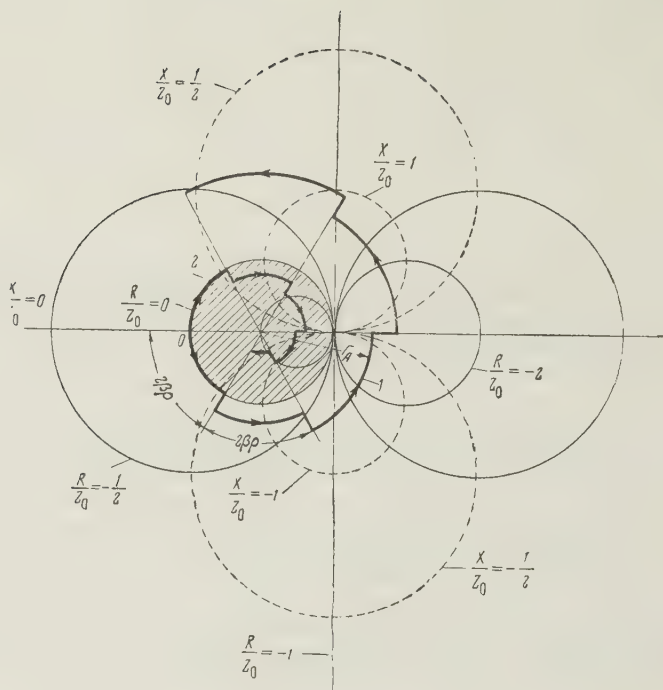


Figure 1. System of orthogonal circles for $\infty > \frac{R}{Z_0} > -\infty$

is the coefficient of reflection (more correctly, the growth coefficient) of the wave at the location where the negative resistor is connected. It can be easily seen that when $|R| \neq 0$ $g > 1$. In the special cases $\Gamma_L = 1$, $l = 0, \lambda/2, \lambda, \dots$, and $\Gamma_L = -1$, $l = 1/4 \lambda, 3/4 \lambda, \dots$ the formula (2) becomes the simpler relation

$$\Gamma_A = g e^{-2j\beta z}. \quad (3)$$

Here the amplitude of the reflected wave turns out to be greater than that of the incident wave, i.e.,

$$\Gamma_A = \frac{E^-}{E^+} > 1.$$

As shown in the work [2], the examined case may be transformed to the problem of reflection from a positive resistance, if the direction of large power flow is taken as the direction of incidence. In the present case, the energy is distributed from right to left, so that one may introduce a certain equivalent passive coefficient of reflection

$$\Gamma_p = \frac{E^+}{E^-} = \frac{1}{\Gamma_A}, \quad (4)$$

or

$$|\Gamma_p| |\Gamma_A| = 1, \quad \varphi_A = -\varphi_p. \quad (5)$$

The conformal transformation of the type (5) in the complex plane is an inversion forcing any point outside the unit circle into this circle. Hence, for the transformation of impedance in the circuit of Figure 2, one may utilize the common circular chart under the condition that the modulus and phase of the coefficient of reflection of the equivalent passive line be found from relation (5). Also, in distinction from the usual case, the center of the chart will correspond to self-exciting operation of the system ($\Gamma_A = \infty$).

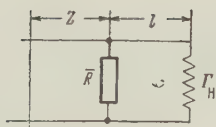


Figure 2. Loaded line with one negative resistor.

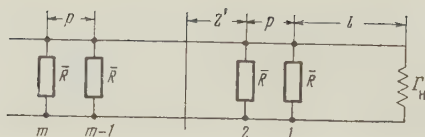


Figure 3. Loaded line with a network of identical negative resistors.

2. A NETWORK WITH A SET p OF m IDENTICAL NEGATIVE RESISTORS R IS CONNECTED INTO A LOADED LINE WITH A COEFFICIENT OF REFLECTION Γ_L

The coefficient of reflection in the n -th interval of such a line (Figure 3) may be written in the form

$$(\Gamma_A)_n = \sum_{n=1}^{n=m} \left(\frac{g}{2}\right)^n e^{-2j\beta z} + \left(\frac{g}{2}\right)^m \Gamma_L e^{-2j\beta(z-l)}, \quad (6)$$

where

$$z = z' + (n-1)p;$$

$$p \geq z' \geq 0;$$

$$\beta = \frac{2\pi}{\Lambda};$$

Λ is the wavelength in the line; g is the coefficient of reflection from each element, determined as in (2).

It is easily seen that in the examined line the coefficient of reflection decreases with distance from the source. The amplitude of the wave in the line is increased upon each passage through an element by $g/2$. Inversion may be performed by constructing a passive line in which at the reflection points $g_p(g/2)^n = 1$. The transformed coefficient of reflection, constructed outside the unit circle, will be represented as an unfolding step curve 1 (Figure 1). Inversion, which permits us to utilize the usual chart, is represented by Curve 2 inside the unit circle.

3. THE LINE HAS A UNIFORMLY DISTRIBUTED NEGATIVE RESISTANCE

Such a system may be realized, for instance, in a traveling wave tube in which the growth in amplitude of the spreading wave obeys the condition

$$E^+ = E_0^+ e^{-\alpha z} e^{j\beta z}, \quad (7)$$

where α is the growth coefficient of the wave, which in the theory of the traveling wave tube depends on the current in a bunch, the voltage and impedance of the coupling in the system; z is the lengthwise coordinate, as measured from the load to the left; E_0^+ is the initial amplitude of the incident wave.

The reflected wave does not interact with the electron flow, and, therefore, the reflection coefficient can be written as

$$\Gamma_A = \frac{\Gamma_L E_0^+ e^{-j\beta z}}{E_0^+ e^{-\alpha z} e^{j\beta z}} = \Gamma_L e^{\alpha z} e^{-2j\beta z}. \quad (8)$$

As in the previous case, the coefficient of reflection decreases toward the load, but smoothly and without discontinuities. Since in the equivalent passive line the change in the coefficient of reflection will be determined from the relation $|\Gamma_p| = |\Gamma_L| e^{-2\alpha p z}$, consequently, the condition for inversion (5) may be obtained only if $\alpha = 2\alpha_p$ and $\Gamma_L = \pm 1$.

Hence, in the case of an arbitrary load, use of the outside portion of the circular chart is recommended. The curve of the change in impedance will take the form of a spiral, evolving from a circle with a radius Γ_L and exiting beyond the borders of the unit circle. As a basis for the construction of such a curve, besides the relation (8), the results of measurements of the amplitude of the growing wave along the axis of the system performed on an operating traveling wave tube may be also used, as in the description in [3].

The generalization of the circular impedance chart examined above may be of use in the choice of locations at which matching elements and energy inputs and outputs may be connected into active channels and in other similar problems.

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INVESTIGATION OF THE ELECTRIC FIELD OF A DENSE BUNCH OF CHARGED PARTICLES

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We give the results of an analytical investigation of the electric field of a dense bunch of charged particles.

INTRODUCTION

A study of the electric field of a dense bunch of particles which takes into account the influence of a conductive shield is of great significance in solving the general problem of the bunching of charged particles.

In this paper we analyze the electric field of a bunch (packet) with a uniform distribution of space charge density, situated inside the metallic shield. The general field expressions obtained enable us to make an analogous calculation in the case of an arbitrary inhomogeneous axially symmetrical charge distribution.

1. CALCULATION OF THE ELECTRIC FIELD OF A PACKET

Calculation of the electric field, created by an axially symmetrical space charge distribution situated inside a metallic shield is made, using Poisson's equation,

$$\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial U}{\partial r} \right) + \frac{\partial^2 U}{\partial z^2} = - \frac{4\pi\rho}{\epsilon}.$$

Its solution is obtained using the Hankel integral transform method with finite limits [1] (p. 104). Multiplying the left- and right-hand sides of the equation by $rJ_0(\lambda_i \frac{r}{a})$ (J_0 is a zeroth order Bessel function; λ_i is the i -th zero of this function; a is radius of the screen) and integrating with respect to r from zero to a , we find that the Hankel transform of the potential function

$$U_J = \int_0^a U J_0\left(\lambda_i \frac{r}{a}\right) r dr$$

will satisfy the differential equation

$$\frac{d^2 U_J}{dz^2} - \left(\frac{\lambda_i}{a}\right)^2 U_J = -\lambda_i J_1(\lambda_i) U(a) - \frac{4\pi}{\varepsilon} \rho_J, \tag{1}$$

where J_1 is a zeroth order Bessel function of the first kind; ρ_J is the transformed space-charge-density function determined from the expression

$$\rho_J = \int_0^a \rho J_0\left(\lambda_i \frac{r}{a}\right) r dr.$$

To obtain the desired solution of Poisson's equation, it is sufficient to determine the value of the transformed potential function from Equation (1) and substitute it into the inversion formula for the Hankel transform with finite limits [1] (p. 105):

$$U = \frac{2}{a^2} \sum_i U_J \frac{J_0\left(\lambda_i \frac{r}{a}\right)}{[J_1(\lambda_i)]^2}.$$

Here the summation is carried out over positive values of λ_i . Without loss in generality of the solution, one may take the potential of the shield surrounding the stream equal to zero, i.e., $U(a) = 0$. Then Equation (1) is simplified and written as

$$\frac{d^2 U_J}{dz^2} - \left(\frac{\lambda_i}{a}\right)^2 U_J = f(z), \tag{2}$$

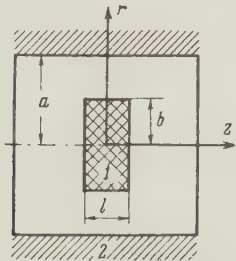
where

$$f(z) = -\frac{4\pi}{\varepsilon} \rho_J.$$

The solution of this equation may be found in the form [2] (p. 210)

$$U_J = \int_{-\infty}^{+\infty} \Gamma(z, \xi) f(\xi) d\xi, \tag{3}$$

Figure 1. Packet of charged particles (1) inside a metal shield (2).



$-\infty < z < +\infty$ (corresponding to the conditions of this problem), has the form [2] (p. 527)

$$\Gamma(z, \xi) = -\frac{a}{2\lambda_i} e^{-\frac{\lambda_i}{a}|z-\xi|}. \tag{4}$$

Substituting expressions (2) and (4) into (3), we find for U_J the equation

$$U_J = \frac{4\pi a}{2\varepsilon\lambda_i} \int_{-\infty}^{+\infty} \rho_J e^{-\frac{\lambda_i}{a}|z-\xi|} d\xi,$$

in which the integration extends over all values of ξ for which the function ρ_J differs from zero. Substituting this equation into the inversion formula, we obtain

$$U = \frac{4\pi}{\varepsilon a} \sum_i \frac{J_0\left(\lambda_i \frac{r}{a}\right)}{\lambda_i [J_1(\lambda_i)]^2} \int_0^{\frac{\lambda_i}{a} |z-\zeta|} \rho_J e^{-\lambda_i \zeta} d\zeta. \quad (5)$$

This expression gives the general form of the potential due to the space charge, the distribution density of which is axially symmetrical.

In the special case of a homogeneous bunch of charged particles, situated inside a metal shield (Figure 1) and having a homogeneous space-charge density distribution ($\rho = \text{const}$), expression (5) will have the following form:

$$U = \frac{8\pi b a \rho}{\varepsilon} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^3 [J_1(\lambda_i)]^2} \varphi(\lambda_i, z), \quad (6)$$

where b is the packet radius; $p = b/a$;

$$\varphi(\lambda_i, z) = \begin{cases} 1 - e^{-\lambda_i \frac{l}{2b} p} \operatorname{ch} \lambda_i \frac{z}{b} p, & |z| \leq \frac{l}{2}, \\ e^{-\lambda_i \frac{|z|}{b} p} \operatorname{sh} \lambda_i \frac{l}{2b} p, & |z| \geq \frac{l}{2}, \end{cases} \quad (7)$$

l is the packet spread.

Hence, the transverse (radial) and longitudinal components of the electric field intensity, respectively, are

$$E_r = \frac{8\pi b \rho}{\varepsilon} \sum_i \frac{J_1\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^2 [J_1(\lambda_i)]^2} \varphi(\lambda_i, z), \quad (8)$$

where $\varphi(\lambda_i, z)$ is determined by expression (7):

$$E_z = \frac{8\pi b \rho}{\varepsilon} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^3 [J_1(\lambda_i)]^2} \psi(\lambda_i, z), \quad (9)$$

where

$$\psi(\lambda_i, z) = \begin{cases} e^{-\lambda_i \frac{l}{2b} p} \operatorname{sh} \lambda_i \frac{z}{b} p, & |z| \leq \frac{l}{2}, \\ \frac{z}{|z|} e^{-\lambda_i \frac{|z|}{b} p} \operatorname{sh} \lambda_i \frac{l}{2b} p, & |z| \geq \frac{l}{2}. \end{cases} \quad (10)$$

Using the superposition principle, the expressions obtained can also be used to calculate the field of a periodic sequence of packets.

2. LONGITUDINAL ELECTRIC FIELD COMPONENT OF THE PACKET

We will investigate the dependence of the longitudinal field component of the packet on the different quantities in expression (9).

1. The change in E_z inside the packet is determined by the expression

$$E_z|_{z \leq 0, 5l} = \frac{8\pi b \rho}{\varepsilon} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^3 [J_1(\lambda_i)]^2} e^{-\lambda_i \frac{l}{2b} p} \operatorname{sh} \lambda_i \frac{z}{b} p. \quad (11)$$

When $z \ll l$ and $z \ll b$ in connection with a rapid convergence of series and when the equality $\operatorname{sh} \lambda_i \frac{z}{b} p \approx \lambda_i \frac{z}{b} p$ holds, one may to a sufficient degree of accuracy, express the field by formula

$$E_z = \frac{8\pi b\rho}{\varepsilon} \frac{J_0\left(\lambda_1 \frac{r}{b} p\right) J_1(\lambda_1 p)}{\lambda_1 [J_1(\lambda_1)]^2} e^{-\lambda_1 \frac{l}{2b} p} \frac{p}{b} z. \quad (12)$$

Hence, it follows that in the central part of the packets the variation of E_z along the radius will be determined by the cylindrical function $J_0\left(\lambda_1 \frac{r}{b} p\right)$, and along the axis - by a linear function of z , independently of the ratio of packet dimensions l/b .

2. For a longitudinal field component at the packet boundary ($z = 0.5l$), one may transform formula (11) to the expression

$$E_z|_{z=0.5l} = \frac{4\pi b\rho}{\varepsilon} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^2 [J_1(\lambda_i)]^2} \left(1 - e^{-\lambda_i \frac{l}{b} p}\right). \quad (13)$$

In that case when the packet dimensions are determined by the ratio $l/b \geq 1$ and the degree of filling of the shield by them is great, the exponential term of expression of (13) is considerably less than unity. Then

$$E_z|_{z=0.5l} = \frac{4\pi b\rho}{\varepsilon} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^2 [J_1(\lambda_i)]^2}. \quad (14)$$

If the packet radius b equals the shield radius a , i.e. $p = 1$,

$$E_z|_{z=0.5l} = \frac{4\pi b\rho}{\varepsilon} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b}\right)}{\lambda_i^2 J_1(\lambda_i)}. \quad (15)$$

It follows from the expressions obtained that the field of a long packet does not depend on its spread l . The largest value of E_z occurs on the axis of the packet, i.e., at the point with coordinates $z = 0.5l$ and $r = 0$. In particular, for packets in which $l/b \geq 1$ and $p = 1$, it will be determined by the expression

$$E_z|_{z=0.5l} = \frac{4\pi b\rho}{\varepsilon} \sum_i \frac{1}{\lambda_i^2 J_1(\lambda_i)}. \quad (16)$$

The ratio of expressions (15) and (16) shows that the radial variation of the relative value of the field E_z/E_{z0} at the boundary of a long packet does not depend on the ratio l/b . It is found empirically that this variation can be expressed very accurately by the function (Figure 2) $\left[J_0(2.4 \frac{r}{b})\right]^{1/2}$. The field at the packet boundary, may be appropriately compared with the field at the boundary of a packet having an infinitely large radius ($b = \infty$), the magnitude of which is determined by the expression

$$E_z|_{b=\infty} = \frac{4\pi\rho}{\varepsilon} \frac{l}{2}. \quad (17)$$

It follows from the ratio of expressions (13) and (17) that the relative value of the packet longitudinal field equals

$$E'_z|_{z=0.5l} = \frac{E_z|_{z=0.5l}}{E_z|_{b=\infty}} = \quad (18)$$

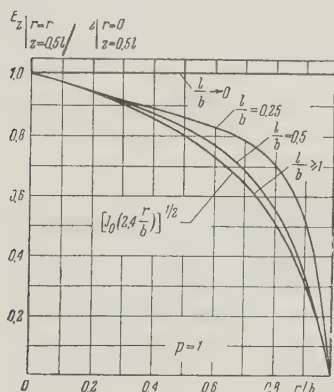


Figure 2. Graph of the variation of the longitudinal field component on its end boundary ($z = 0.5l$) as a function of radial coordinate.

The curve of function $[J_0(2.4 \frac{r}{b})]^{1/2}$ virtually coincides with the curve corresponding to $l/b \geq 1$.

$$2 \frac{b}{l} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b} p\right) J_1(\lambda_i p)}{\lambda_i^2 [J_1(\lambda_i)]^2} \left(1 - e^{-\lambda_i \frac{l}{b} p}\right). \quad (18)$$

In the case of a long packet ($l > b$), the field E'_z will vary in direct proportion with b/l (Figure 3).

We will investigate the field E_z at the boundary of narrow packets. From the ratio of expressions (11) and (17) at $z = 0.5l$ and $p = 1$ we find

$$E'_z|_{z=0.5l} = \frac{2b}{l} \sum_i \frac{J_0\left(\lambda_i \frac{r}{b}\right)}{\lambda_i^2 J_1(\lambda_i)} e^{-\lambda_i \frac{l}{2b} \text{sh} \lambda_i \frac{l}{2b}}, \quad (19)$$

whence it follows that as $l/b \rightarrow 0$,

$$\frac{\text{sh} \lambda_i \frac{l}{2b}}{\lambda_i \frac{l}{2b}} \Big|_{l/b \rightarrow 0} \rightarrow 1; \quad e^{-\lambda_i \frac{l}{2b}} \Big|_{l/b \rightarrow 0} \rightarrow 1,$$

the expression for the field at the boundary of a narrow packet ($l/b \rightarrow 0$) is written in the form

$$E'_z|_{z=0.5l} = 2 \sum_i \frac{J_0\left(\lambda_i \frac{r}{b}\right)}{\lambda_i J_1(\lambda_i)} = 1. \quad (20)$$

Equation (20) follows from the fact that the series

$$\sum_i \frac{J_0\left(\lambda_i \frac{r}{b}\right)}{\lambda_i J_1(\lambda_i)} = \frac{1}{2}$$

for all values $r < b$ [1] (p. 206).

Thus, the longitudinal field component of a critically narrow packet does not depend on the radial coordinate and at any point on the packet boundary, besides points $r = b = a$, is equal

numerically to the field of a packet with an infinitely large radius. Near the point $r = a$ the field E_z decreases in steps to zero.

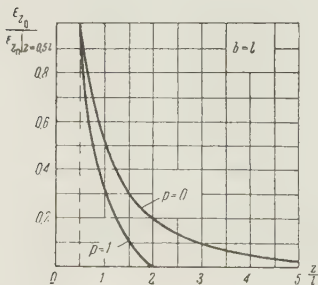


Figure 3. Graph of the variation of the maximum relative values of the axial and radial field components of a packet as a function of the ratio of packet dimensions, calculated from Equations (18) and (22) (solid curves) and from Equation (21) (dashed curve).

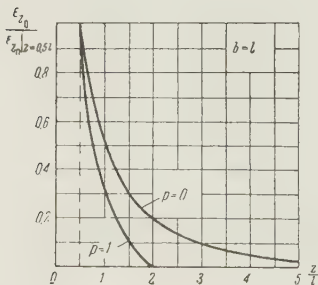


Figure 4. Graph of the field variation along the packet axis with ($p = 1$) without ($p = 0$) a shield.

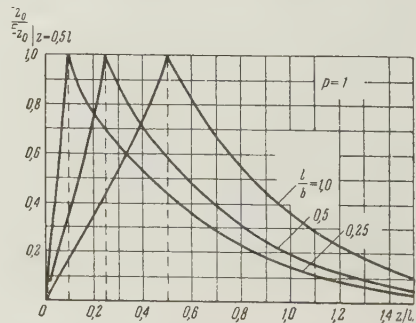


Figure 5. Graph of the variation of the axial component of field inside and outside the packet.

So, the results of a study of the field at the boundary of a packet show that, as a function of the ratio of packet dimensions l/b , the relative value of the longitudinal component of field on the packet axis can vary from zero to a value equal to the field of a packet with an infinitely large radius.

To determine the effect of a shield on the axial field on the boundary of the packet ($z = 0.5l$), the field was computed as a function of the ratio l/b for both limiting cases: when the shield is adjacent to the lateral surface of the packet ($p = 1$) and when the screen is removed to infinity (Figure 3). In the first case expression (19) was used for the calculation with $r = 0$ and in the second case, the known expression of [3] (p. 57)

$$E_z' = 1 + \frac{b}{l} \sqrt{\left(\frac{z}{b} - \frac{l}{2b}\right)^2 + 1} - \frac{b}{l} \sqrt{\left(\frac{z}{b} + \frac{l}{2b}\right)^2 + 1} \quad (21)$$

with $z = 0.5l$.

It is apparent from a comparison of the curves that the shield noticeably influences the axial field of the packet only in long packets ($l > b$).

3. Investigation of the field E_z outside the packet shows that the longitudinal component of the field at $z > 0.5l$ decays rapidly with coordinate z , the rate of attenuation depending on the presence of the shield. When the shield is adjacent to the lateral surface of the packet, the field at the axis of the packet E_z is almost completely absent at all points at a distance of $z > 2b$ from the packet center (Figure 4). The variation of field E_z as a function of coordinate z for several values of l/b is shown as curves in Figure 5.

3. RADIAL COMPONENT OF ELECTRIC FIELD OF THE PACKET

The radial field of the packet E_r can be calculated from formula (8). Investigation shows that the maximum value of this field occurs at the center of the lateral boundary surface of the packet ($r = b$, $z = 0$).

Figure 3 presents the dependence of the maximum radial electric field of the packet E_r' on the ratio of packet dimensions l/b . The field E_r' is defined as the ratio of (8) to the field of an infinitely long packet

$$E_r' = \frac{E_r|_{r=b}}{E_{r\infty}|_{z=0}} = \frac{E_r|_{r=b}}{\frac{2\pi\rho_0}{\epsilon}b} \quad (22)$$

As should be expected, the radial field of the packet of finite length is less than the field of an infinitely long packet.

When we consider, however, that the space charge density in the packet can be several times greater than the density of the volume charge in the absence of bunching, it must be assumed that the value of the defocusing radial forces acting on the peripheral electrons of the packet, can appreciably exceed the value of these forces in an unexcited stream.

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STUDY OF THE SHAPE OF W_2C SINGLE CRYSTAL EMITTERS USING AN ELECTRON MICROSCOPE

Yu. V. Zubenko

W_2C emitter points were observed in an electron microscope.

Shadow patterns of the tip of the point showed that the apex of tungsten carbide single crystal points are rounded, not like a symmetrical hemisphere, but of a more complicated curvature.

Within the resolving power of the electron microscope, no flat sections were found on the point apex.

During carbidization, there is pronounced deformation of the tip of the point.

1. STATEMENT OF THE PROBLEM

On a field emission projector screen, we observed a transition from a cubic body - centered tungsten lattice to a hexagonal lattice of tungsten carbide, W_2C , occurring in a single crystal situated at the apex of the emitter point [1, 3].

It was observed that when the diagram corresponding to W_2C emerged, field emission began at a reduced voltage. Since the work function of tungsten carbide apparently equals the work function of tungsten, the voltage decrease can be caused only by an increase of local field strength in the point due to a change in the surface structure [2]. In papers studying the carbidization of tungsten wires [4-7] it was also pointed out that, during carbidization, the surface structure of wires changes appreciably.

For an emission picture obtained from a W_2C point (Figure 1b), the existence of two strongly emitting regions is characteristic: a region in the neighborhood of the fundamental face, and a region of the lateral faces (1100), (1210) of a hexagonal prism. These regions are separated by an area from which there is practically no emission.

If the surface of a W_2C crystal is coated with thorium or barium, which reduces the work function of tungsten carbide, emission emerges from the dark section only in the case of very large deposits [2]. At the same time, thorium and barium are readily adsorbed in the vicinity of the base and on the lateral faces, where emission increases.

On the basis of these observations, one may put forward the following hypotheses concerning the structure of the emitting surface of a W_2C crystal: 1) the strongly emitting regions are most likely protuberances formed as a result of structure changes during carbidization; the protuberances emerge along the characteristic directions of a hexagonal lattice, and build up from faces of a hexagonal prism; 2) a nonemitting section may correspond to a depression on the crystal lattice or even a hollow; therefore the local field here is so small that even a substantial decrease in the work function does not give rise to emission; however, a large quantity of thorium or barium, besides decreasing the work function, possibly also increases the local field, and emitting sections are observed in the dark gap.

This paper is devoted to clarifying the actual configurations of an emitting point tip of tungsten carbide.

2. PREPARATION OF SAMPLES AND RESULTS OF THE OBSERVATIONS

Single crystalline tungsten points, fastened onto the arc from a tungsten wire of diameter 0.1 mm, were transformed to W_2C single crystals by the method of [2]. The transformation was inspected by means of an emission pattern and was regarded as completed when the tungsten carbide picture (Figure 1b) appeared instead of the pure tungsten picture (Figure 1a).

The dimensions of the original tungsten points varied within limits: length, 1.4 - 1.7 mm and radius of curvature, 0.3 - 0.5 microns.

The carbide points were removed from the projector, glued into the mounting of the electron microscope and disconnected from the arc.

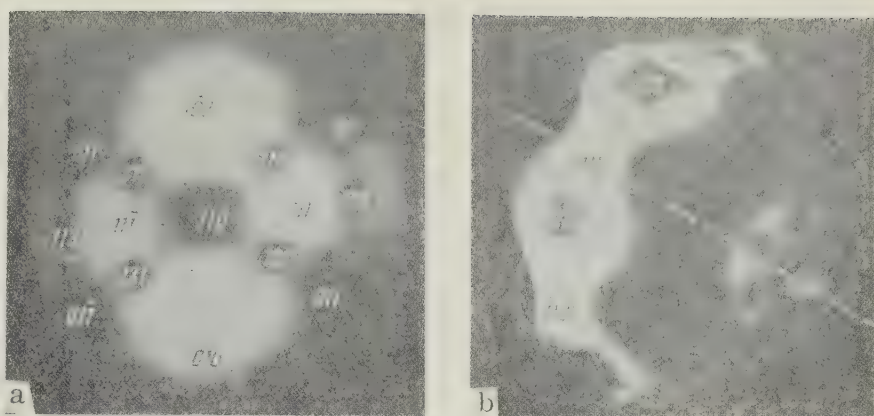


Figure 1. Field emission patterns: a) pure tungsten; b) tungsten carbide, W_2C .

In electron microscope EM-3, it is possible to observe a shadow pattern of the W_2C point apex. The plane of the shadow pattern runs along the direction designated in Figure 1b. Figures 2b through e show several such patterns typical for W_2C single crystalline points. In

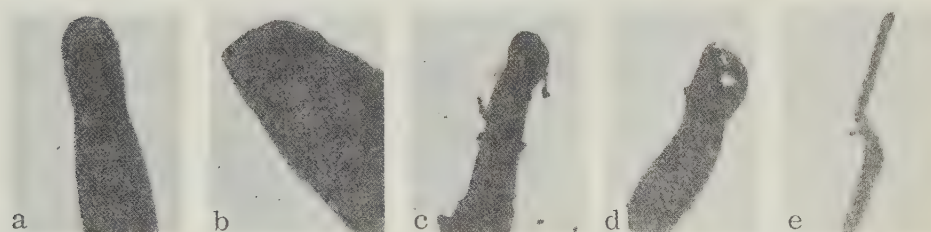


Figure 2. Emitter points visible in the electron microscope: a) transformed tungsten point, X 20,000; b) W_2C point X 18,000-20,000; c-e- W_2C point, X 10,000.

these photographs it may be clearly seen that the surface of a W_2C point is just as smooth as a pure tungsten point (Figure 2a). Within the limits of the microscope's resolving power, no protuberances or hollows were observed. However, if the apex of the tungsten point, baked in a vacuum or transformed in a field, is hemispherical in form and is symmetrical relative to the axis of the point, the apex of the carbide point is highly unsymmetrical.

The emission picture in the first case is arranged symmetrically relative to the center of the screen. In the second case the picture is always shifted to the side, and its center of symmetry does not coincide with the center of the screen.

Neglecting possible distortions of the electric field in the projector, one may assume that the details of the emission picture are distributed precisely above definite sections of the emitting surface. Thus, our assumption of the shape of the W_2C point apex is in good agreement with the emission picture. The section of the surface of the point apex having the greatest curvature corresponds to the lateral face region. Along the $[1000]$ direction, the surface has



Figure 3. W_2C point visible in the optical microscope. $\times 60$.

to I. L. Sokol'skaya for her valuable advice and interest in the work as well as to M. I. Rudenko for his help in the electron microscope work.

least curvature and is separate from an intermediate space region having a very small curvature. The dark region between the base and lateral face corresponds to this intermediate space on the emission picture.

Depressions are not usually observed on such points. It should be noted that on the shadow picture, the parts of the surface of the point which are disc-shaped, will appear as depressions, only when their planes appear to be perpendicular planes of the shadow picture. The probability of such a fortunate arrangement apparently is very small. Only in one case did we succeed in observing a flat section on the surface of a point (Figure 2C). Fifteen W_2C points in all were studied.

During carbidization the tungsten points are noticeably deformed. The thin part, directly adjoining the apex, is bent many times. This is all too apparent from Figure 2e, and the photograph (Figure 3) obtained in an optical microscope.

The author expresses his sincere gratitude

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EFFECT OF ADSORPTION ON THE RESISTANCE OF THIN METAL FILMS Pt. II. ELECTROPOSITIVE ATOMS

Yu. G. Ptushinskiy

A study was made of the influence of adsorption of cesium and barium atoms on the resistance and work function of thin film deposits of nickel and tungsten. While adsorption leads to an appreciable decrease in the work function, it does not lead to a marked change in film resistance.

In cathode electronics, the subject of the mechanism of the influence of adsorption of active films on the work function of solids is very important. Reference [1] describes the results of a study of the influence of adsorption of dipolar molecules BaO and CsCl on the resistance and work function of thin films (mainly metallic), in order to obtain certain information about electron interaction in such systems and its role in the mechanism of the decrease of work function with adsorption.

Similar studies conform completely with these same laws in the case of adsorption of alkali and alkaline-earth atoms. This phenomenon [2, 3] is accompanied by an appreciable decrease in work function.

Voluminous experimental material has been published in the literature on the effect of gaseous molecules (as a rule, electropositive) on the resistance of thin metallic films (for example, [4-7]), but no data exists concerning the adsorption of electropositive alkali and alkaline-earth atoms. This circumstance makes it most reasonable to carry out similar studies of the adsorption of alkali and alkaline-earth atoms.

This paper is devoted to a study of the influence of adsorption of barium and cesium atoms on the resistance and work function of thin film deposits of the transition metals nickel and tungsten, and also to a study of the influence of the adsorption of barium on the resistance of nickel films previously coated with a certain amount of oxygen (in mono-molecular layers).

The design and technique of manufacturing experimental tubes, the technology of preparing the films, and also the measurement technique were those of [1]. Consequently, we will not describe them, but we will say a few words about atomic beam sources.

The barium source was a tantalum tube, heated by the passage of current and having an orifice for the outlet of an atomic beam, filled with crushed getter tablets BATI. The good quality of such a source was verified mass-spectrometrically. As a cesium source we used cesium drops placed in a carefully evacuated glass ampoule. In order to deposit cesium, the ampoule was broken and the extension in which it was located was heated up slightly.

Adsorption of barium and cesium atoms was carried out at a metallic film temperature of $\sim 78^\circ \text{K}$. The film thickness was $\sim 10^{-6} \text{ cm}$. The investigations were performed at a residual gas pressure of $2 - 10^{-9} \text{ mm Hg}$.

Figure 1 gives the simultaneously measured variations of the work function (curve φ) and resistance (curve R) of the nickel film as a function of the time required for depositing barium atoms. As may be seen from the figure, the work function of a nickel film during adsorption of barium atoms decreases approximately the same as in the Ba-W system [8].

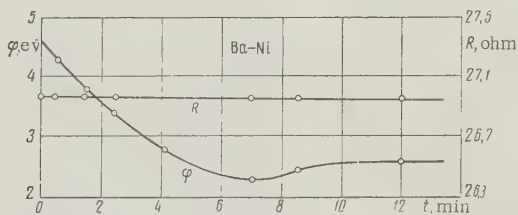


Figure 1. Dependence of φ and R of a nickel film on the time for depositing barium.

In this case a minimum occurs in the curve of the function $\varphi(n)$ (n - is the concentration of adsorbed atoms, which in this case is proportional to the deposition time). It is also apparent from Figure 1 that the nickel film resistance remains constant during adsorption of barium atoms. With greater deposition of barium, the resistance decreases - a fact related to the shunting action of the layer of adsorbed atoms, which however is of no interest and, consequently, in Figure 1 and succeeding figures is not shown.

Figure 2 gives the variations of the work function and resistance (curves φ and R, respectively) with the time for depositing cesium atoms. We see that in this case a decrease of the work function by $\sim 3 \text{ eV}$ is not accompanied by a change in resistance.

A similar result was obtained when depositing cesium on a pure tungsten film (Figure 3) and depositing barium on a nickel film (Figure 3) previously covered with oxygen (so that its work function increased by 0.6 eV).

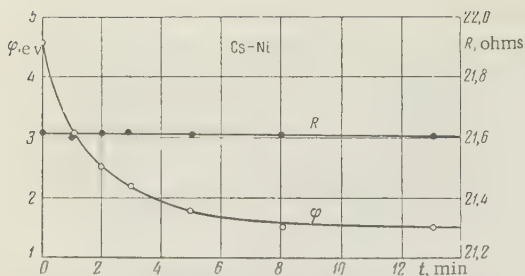


Figure 2. Dependence of ϕ and R of a nickel film on the time for depositing cesium.

resistance occurs as a result of a change in the conditions for electron scattering at the film surface, caused by adsorption of such molecules.

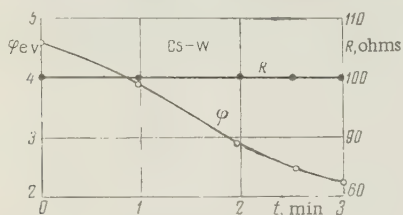


Figure 3. Variation of ϕ and R of a tungsten film with the time of deposit of cesium.

adsorbed atoms is very small, and the change in work function occurs as a consequence of the corresponding polarization of adsorbed atoms. However, a more careful consideration of the data shows that it alone while not in contradiction with this point of view, does not give sufficient basis for confirming it.

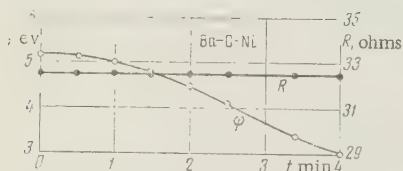


Figure 4. Variation of ϕ and R of a nickel film, covered by oxygen, with the time of deposit of barium.

Thus, the appreciable decrease in the work function of a metallic film during adsorption of cesium and barium atoms is not accompanied by a change in their resistance. However the given data by itself does not allow us to reach a definite conclusion concerning the mechanism of change of the work function. For this purpose it is necessary to seek results of other experiments.

In conclusion the author expresses his gratitude to N.D. Morgulis for his attention and interest in the work.

Thus, without exception, in all the experiments that we performed with the system Ba-Ni, Cs-Ni, Ba-O-Ni and Cs-W, a substantial decrease in work function was not accompanied by a change in the electrical resistance of the film.

It was shown in [1] that the adsorption of molecules BaO (and CsCl) together with the reduction in work function of metallic films leads to an increase in their resistance, which, however, is not related to a change in electron concentration in the film and thus, probably, is not the result of electron interaction. It is suggested that the change in

resistance occurs as a result of a change in the conditions for electron scattering at the film surface, caused by adsorption of such molecules. In contrast with this phenomenon, adsorption of cesium and barium atoms, apparently does not lead to a significant change in the condition for electron scattering. One may hardly assume in all cases that an increase in film resistance due to a change in the conditions of electron scattering at the surface is precisely compensated by a resistance decrease due to an electron jump (if it should occur).

At first glance, the absence of a change in film resistance with so substantial a decrease in its work function would seem to indicate that the average degree of ionization of ad-

Actually one may say that, in spite of the fact that the appreciable average degree of ionization of the adsorbed atoms causes a decrease in the work function and, undoubtedly, an increase in the electron concentration near the film surface (these electrons screen the charges located on the surface of positive ions), the film resistance does not change materially as a consequence of the very small mobility of these electrons, due to the presence of positive ions on the surface, in comparison with the mobility of conduction electrons inside the material.

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ON THE MECHANISM OF FORMATION OF A LOW-PRESSURE, HIGH-FREQUENCY DISCHARGE IN AIR

G.N. Zastenker, G.S. Solntsev and B.N. Shvilkin

The process of formation of a low-pressure, high-frequency discharge in air is studied by means of oscillographs of the discharge current and the luminous intensity. We propose a steady-state mechanism at the base of which is a concept of two stages of development of the discharge. During the first stage, the electric field in the entire discharge space is uniform. In the second stage the high-frequency voltage is redistributed between the intermediate region and the region of the discharge space near the electrodes.

Experimental data concerning the duration of both stages are found to be in qualitative agreement with the expounded theory.

INTRODUCTION

On the basis of experimental data on the development of a low pressure high-frequency discharge [1], the formation time of the discharge¹ can be divided into two parts: the time during which electron concentration rises exponentially (t_{exp}), and the time during which the growth in concentration slows down and establishes its stationary value.

The literature [3, 4, 2] points out a method of calculating the ignition voltage V_i and t_{exp} under the assumption that elementary processes in the discharge during this stage are related only to the high-frequency field in the discharge space, which does not change in magnitude during the development of the discharge. However on the basis of this assumption, it is impossible to determine the ignition voltage and total formation time t_{form} . The magnitude of the high-frequency voltage necessary to maintain a constant electron concentration in the discharge is calculated for hydrogen and argon. The question of the length of time required to establish a constant concentration at the present time remains unanswered. The solution of this problem is connected with the analysis of such factors retarding the growth of the electron concentration, as: redistribution of the high-frequency field in the discharge space, the formation of space charge, etc. The effect of the first of these factors on the behavior of the volt-ampere characteristic of the steady-state discharge was investigated for a discharge in air in [5].

¹By formation time t_{form} we mean the time from the appearance, in the discharge space, of a free electron capable of causing breakdown, to the establishment of a steady state.

In this paper we give experimental data on the study of the formation of a low pressure high-frequency discharge in air. A calculation is given of the formation time, based on the assumption that the establishment of a stationary discharge occurs as a result of a redistribution of the high-frequency voltage.

1. EXPERIMENTAL RESULTS

A study of the formation time of the high-frequency discharge is carried out in air at pressures 0.4–30 mm Hg and field frequencies 12.0; 6.0 and 3.3 Mc in a tube with disc-shaped outer electrodes (electrode diameter 70 mm, interelectrode separation 21 mm). The formation time was measured by means of oscillograms of the discharge current and luminous intensity of the gas in the discharge space with the aid of technique and apparatus, described previously in [1].

From the oscillogram we determined the time t_{exp} from the initial formation of discharge up to the moment of deviation of the curve of increase of the discharge current or illumination from an exponential curve, and also the total formation time t_{form} . In [1] the formation time is divided into two stages from the standpoint of the possibility of registering a change in state of the gas in the discharge. Physically, however, a more reasonable division of the formation time of the discharge into stages is one based on the prevalence of one or more processes which determine the electron concentration. Therefore, in this paper we use the value of t_{exp} for a comparison of the experimental data with theory.

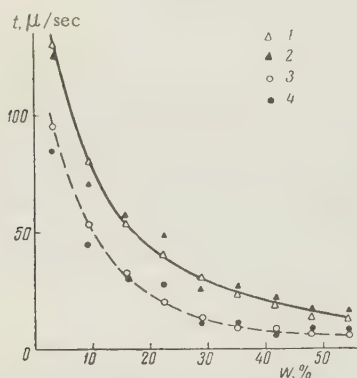


Figure 1. Variation of the time of exponential growth and total time of formation of the discharge as a function of overvoltage $p = 10$ mm Hg, $f = 12$ Mc.

1 - t_{form} from oscillogram of luminous intensity; 2 - t_{form} from oscillogram of discharge current; 3 - t_{exp} from oscillogram of luminous intensity; 4 - t_{exp} from oscillogram of discharge current.

Figure 1 gives the variation of the time of exponential growth and the total time of formation of the high-frequency discharge as a function of overvoltage at pressure 10 mm Hg and field frequency of 12 Mc. Data on the time of formation, obtained from oscillograms of discharge current and gaseous luminosity, do not differ significantly from one another. Analogous results were obtained at other pressures and oscillatory frequencies.

Results of the measurement of total time of formation of the discharge over the entire region of investigated pressures are given in Figures 2 and 3. The complex nature of the curves is explained by the existence, in pressure and field frequency region, of two forms of high-frequency discharge, hereafter called α - and γ -discharges (see [9] and [5]). In an α -discharge, volume processes play the dominant role, and during a transition to a γ -discharge we begin to see electron emission from the glass walls adjacent to the electrodes. These forms of the discharge have different structure. The existence of two forms of discharge explains the emergence of a second minimum on the ignition characteristic (see, for example [10, 9, 11]).

During a transition of one form of discharge to the other, the formation time decreases sharply (for 6 Mc, more than 10-fold). The value of pd corresponding to the transition differs little from the values given in [11] for the jump in ignition voltage. At a frequency of 12 Mc, the α -discharge exists for pressures greater than 0.7 mm Hg, and at the frequency 6 Mc, it occurs for pressures greater than 6 mm Hg.

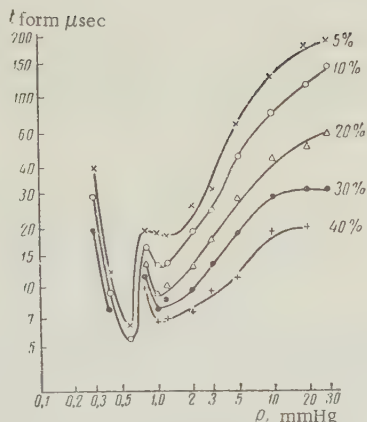


Figure 2. Time of formation of discharge at frequency 12 Mc (the numerals on the curves are overvoltages in %).

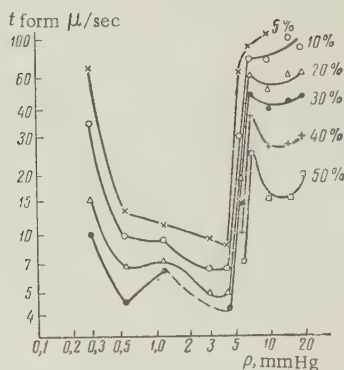


Figure 3. Time of formation of discharge at frequency 6 Mc (numerals on the curves are overvoltages in %).

2. DISCUSSION OF RESULTS

At present, two points of view exist concerning ignition of the discharge, within the frequency range $10^5 - 10^8$ cps. One point of view deals with the process of discharge ignition, taking into account the effect of a positive space charge arising in the space as a consequence of the different inertia of electrons and positive ions (see, for example [7, 8]). Distortion of the field by this charge leads to a variation of the ignition voltage with the frequency of the high-frequency oscillations.

The other group of papers [4, 2, 6] explains the discharge ignition by considering the balance of electrons in the discharge space, under the assumption that the field in the space remains homogeneous during the development of the discharge. Thus, attention is directed to ionization of gas atoms by electron collisions, diffusion of electrons, and the formation of negative ions. Electron drift in the high-frequency field is accounted for as a change in the diffusion length of the discharge space [9, 6]. The effect of the frequency of the high-frequency on ignition voltage of the discharge, in accordance with these concepts, may be caused, first, by a change in the effectiveness of the electric field (i.e., a change in the magnitude of energy transferred to the electron by the field and, secondly, by a change in amplitude of electron oscillations, i.e. a change in the effective diffusion length.

In Figure 4, the breakdown characteristics of the discharge space, obtained at frequencies 6 and 12 Mc are compared with the calculated curve from [4]. No data is given for the frequency 3.3 Mc, because in this case there exists only an γ -discharge which is not describable by this theory. At low pA the curves do not differ significantly, but at large pA the experimental curves lie below the theoretical curve, the maximum discrepancy reaching 20-30%. Obviously, this discrepancy, just as the difference between the results for 6 and 12 Mc, is connected with the fact that the calculation was performed neglecting field distortion by space charge.

The theoretical calculation of the formation time of a high-frequency discharge given below, for simplicity, was carried out neglecting the influence of space charge.

Establishment of a stationary state of a high-frequency discharge under conditions, in which appreciable space charge is formed, may be caused, from our point of view, by a redistribution of the field in the discharge space.

Redistribution of voltage between different regions of the discharge space is caused by the impoverishment by the electrodes of adjacent regions, and signifies, also, a decrease in their conductivity (see [5]). We adopt an idealized picture of concentration distribution such that in the regions adjacent to the electrode, of dimension d_1 , the electron concentration equals zero (a capacitive current flows through them) and in the central part of the discharge space with dimension $d - 2d_1$ (d is the length of the discharge space) the concentration

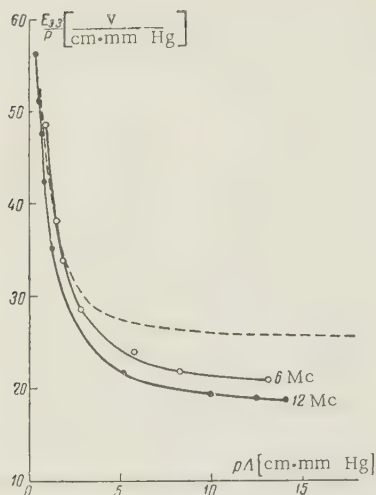


Figure 4. Reduced breakdown intensity of the field. Points - calculated data [4]; solid lines - experimental results.

noticeable change in the field intensity in the central region sets in at concentrations

$$n \simeq \frac{0,1 d \omega_{\text{coll}} m}{8 \pi e^2 d_1}. \quad (2)$$

Up till the moment the growth in concentration starts to follow the exponential law, no retarding factors exist. After reaching such a concentration, according to (1), there occurs a decrease in the field strength of the central region of the discharge and a retardation in the growth of the concentration. At the same time, there arises a redistribution of voltage between this region of the discharge and regions near the electrodes, i. e., the voltage in the central region decreases, but rises in the regions near the electrode. This moment of time corresponds to t_{exp} . The transition to a steady-state includes a drop in the field intensity in the central region to the minimum value necessary to maintain a stationary concentration. If the elementary processes do not change during development of the discharge, this field intensity equals the breakdown intensity (because the balance condition of electrons in the discharge space agrees, in this case, with the breakdown condition). If the character of elementary processes during formation of the discharge changes (for example, rate of diffusion decreases as a consequence of a transition from free to bipolar diffusion), the steady-state field intensity will be less than the breakdown intensity.

The growth in the electron concentration and the drop in field intensity in the central region for two different overvoltages are shown schematically in Figure 5. The transition to a stationary state corresponds to the time t_{form} ; the field intensity has the value E_{stat} at the end of the discharge development and the concentration is n_{stat} .

Thus, according to the accepted hypothesis of the formation of a discharge, during the development of the discharge, the electron concentration increases automatically up to a value that ensures a decrease of the electric field intensity in the central region up to the value E_{stat} . The value E_{stat} is defined by the balance equation, and does not depend on the voltage applied to the tube. The electron concentration n_{stat} in this case will be larger, the higher the applied voltage.

Starting from these concepts, one may calculate the duration of the process of establishing the stationary electron concentration and the variation of this concentration with time.

The solution of the equation of electron balance in the discharge space leads to the following expression for growth of concentration with time:

of electrons is the same at all points, but the conductivity is complex. On the basis of the hypothesis one may obtain [5] a relation between the electric field intensity in the central band E_0 , electron concentration n , and voltage amplitude in the discharge space V_0 :

$$E_0 = \frac{V_0}{\sqrt{d^2 - bn + cn^2}}, \quad (1)$$

$$b = \frac{16 \pi e^2 d d_1}{m (\nu_{\text{coll}}^2 + \omega^2)}, \quad c = \frac{1}{\nu_{\text{cn}}^2 + \omega^2} \left(\frac{8 \pi e^2 d_1}{\omega m} \right)^2,$$

where ω is the field frequency V_{coll} is the collision frequency; e , m are the electron charge and mass.

We will consider processes in the discharge space during the development of a high-frequency discharge.

In the beginning of the formation of the discharge, when the electron concentration is small, the second and third terms under the radical sign in (1) are small in comparison with d^2 . The field intensity at all points of the discharge space in this case is the same. A

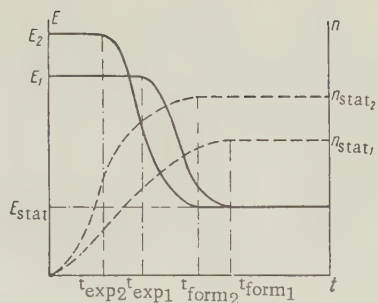


Figure 5. Diagram of the variation in amplitude of the high-frequency field intensity and electron concentration in the central region during development of the discharge.

$$t = \int_{n_0}^n \frac{dn}{n \left[(\nu_i - \nu_c) - \frac{D}{\Lambda^2} \right]}, \quad (3)$$

where n_0 is the initial electron concentration; ν_i is the ionization coefficient; ν_c is the electron-capture coefficient for neutral molecules; D is the diffusion coefficient; Λ is the diffusion length of the discharge region.

During the first stage of formation of the discharge, the field intensity does not change and therefore Equation (3) changes to

$$t = \frac{\ln \frac{n}{n_0}}{(\nu_i - \nu_c) - \frac{D}{\Lambda^2}}. \quad (3a)$$

In this case it is assumed that during the time of exponential growth of the concentration, electron diffusion is free. In Figure 6 we compare the experimental results for t_{exp} with the calculated data given in [4]. Experiment confirms the character of the variation of pt_{exp} with E_c/p , although it does not give precise agreement. At pressures above 5 - 10 mm Hg, the value of pt_{exp} does not depend on pd , which does not indicate the dominant role of electron capture in comparison with diffusion to the walls. Possible reasons for discrepancies are, first, neglect of electron drift and second, neglect of space charge.

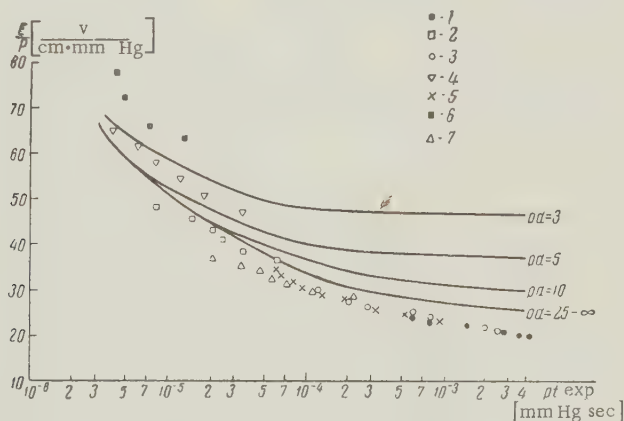


Figure 6. Comparison of experimental and calculate data on the duration of the stage of exponential growth of electron concentration:

solid lines - theoretical curves [4]; experimental points for:

- 1 - $pd = 63$ mm Hg; 2 - $pd = 6.3$ mm Hg; 3 - $pd = 40$ mm Hg; 4 - $pd = 4.2$ mm Hg; 5 - $pd = 21$ mm Hg; 6 - $pd = 2.5$ mm Hg; 7 - $pd = 10.7$ mm Hg.

We will now consider the stage of discharge formation, during which factors act which retard the growth of the electron concentration and conduct the discharge toward a stationary state. In this stage, the field intensity in the central region decreases with time, and therefore in Equation (3) it is impossible to assume that coefficients ν_i , ν_c and D no longer depend on time. Using the relation (1) between the field intensity in the central part of the

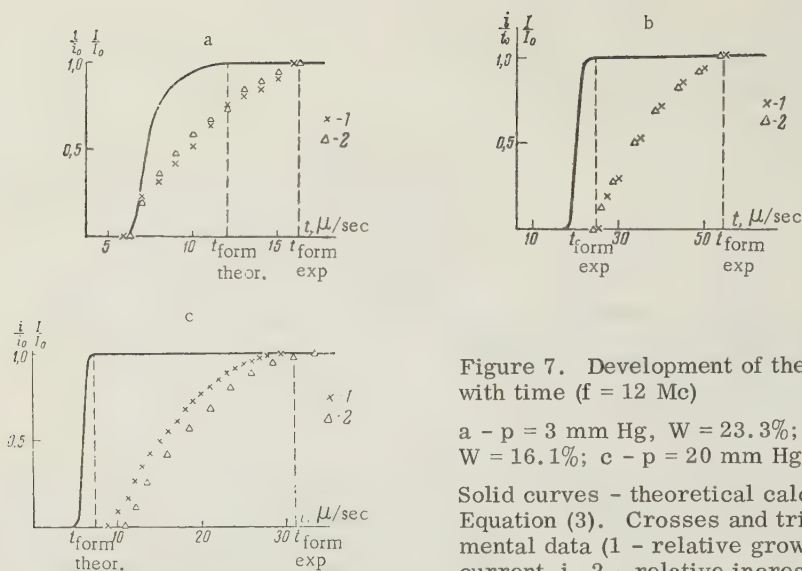


Figure 7. Development of the discharge with time ($f = 12$ Mc)

a - $p = 3$ mm Hg, $W = 23.3\%$; b - $p = 10$ mm Hg, $W = 16.1\%$; c - $p = 20$ mm Hg, $W = 31\%$.

Solid curves - theoretical calculation with Equation (3). Crosses and triangles - experimental data (1 - relative growth of discharge current i , 2 - relative increase of luminous intensity I)

discharge and electron concentration, one may calculate from Equation (3) the time necessary for increase of the concentration up to the stationary value. The variation of $\nu_i - \nu_c$ with field intensity, necessary for calculations for a high-frequency discharge in air, is given in [4]. Furthermore, we will assume that in this stage of discharge development, diffusion is already bipolar. As a consequence, electron capture by molecules of an electronegative gas becomes the predominant process and the term D/Λ^2 in (3) may be neglected. The final concentration at a given voltage in the discharge space is determined from the steady-state condition (growth of the number of electrons due to ionization is compensated by their decrease due to capture, i.e., $\nu_i = \nu_c$). In view of the absence of an analytical variation of $\nu_i - \nu_c$ with field intensity, integral (3) is calculated numerically. The value of d_1 necessary for the calculation was determined by the method indicated in [5].

The results of these calculations and their comparison with experimental data on the time development of the discharge current and luminous intensity are given for different conditions in Figure 7a, b, c. Curves of the relative change in luminous intensity and discharge current agree with one another.

Comparison of the experimental and calculated data shows that the hypothesis concerning the development of a high-frequency discharge allows one to explain the transition to a stationary high-frequency discharge. However there is no quantitative agreement of the theoretical and experimental rate of growth of electron concentration. Actually, the experimental growth in illumination and current occurs 2 - 10 times more slowly than it should according to theory.

One of the possible explanations for this fact is connected with the above-mentioned difference between the calculated and experimental values of the given breakdown field intensity. The discrepancy between the theoretical and experimental values of E_{cc}/p , just as between the corresponding values of the time of formation are larger, the greater is $p\Lambda$ (Figure 4 and 7). Since $\nu_i - \nu_c$ is an increasing function of E/p , the more rapid growth of electron concentration in the theory is explained by the increased values of E_{cc}/p in comparison with experiment.

Thus, the difference between the behavior of the calculated and experimental curves in Figures 4 and 7 may be assumed to be due to the same cause, namely, distortion of the field by space charge.

CONCLUSIONS

1. It was shown experimentally that a) the formation time of a low-pressure, high-frequency discharge in air at given conditions is 5-200 μ sec; b) the transition from α -

discharge to γ -discharge is accompanied by a sharp decrease in formation time.

2. The described mechanism of development of a high-frequency discharge due to redistribution of voltage in the discharge space enables us to explain qualitatively the establishment of a stationary state.

3. Comparison of the time of exponential growth of the luminous intensity and discharge current with theoretical calculations [4] gives satisfactory results.

4. Comparison of the calculated duration of the second stage of the development of the discharge with experiment leads to an appreciable discrepancy (by a factor 2 at pressure 3 mm Hg, and a factor 10 at pressure 20 mm Hg), which indicates the necessity of taking into account, theoretically, the role of space charge especially at large pressures.

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ELECTRIC CURRENT IN PENNING TUBES

I. M. Polyak

An experimental investigation was made of the conditions in which electron current, instead of ion current, flows in the cathode circuit of a Penning tube. A measurement was made of energy of the electrons flowing to the collector.

INTRODUCTION

Penning tubes are used as ionization gauges [1, 2], ion sources [3, 4], and a high-vacuum pumps [5, 6, 7]. In these tubes high-frequency oscillations were observed [7, 8].

The mechanism of the processes that take place in Penning tubes was investigated by Reikhrudel' and his co-workers [9, 10]. The object of investigation was the ion current necessary for normal operation of all the above-mentioned devices.

It was established in our experiments that there exists a certain value of magnetic field strength H for a given anode voltage V_a , at which electron current instead of ion current flows in the cathode circuit. This paper is also devoted to the first result of the investigation of this electron current.

1. DESIGN OF THE TUBE AND ELECTRON KINETICS

Figure 1 gives a diagram of the experimental tube. The cathode is a Venel't cylinder 1 with a small aperture at its end. An incandescent tungsten spiral is placed in the plane of

this aperture. Thus, we have a flat cathode with a source of thermionic emission at its center. An orificed anode 2, a flat electrode 3 grounded through the device and the collector are the conventional electrodes of a Penning tube. The tube is placed in the region of uniform magnetic field of a sufficiently long solenoid. Inside the tube connected to the vacuum system, there is a system of controls on a rubber seal, not indicated in Figure 1, which makes it possible to move the electrodes under vacuum.

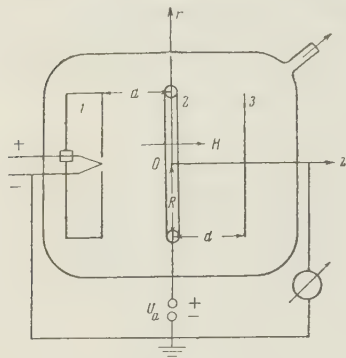


Figure 1

In the paper of Smirnitskaya and Reikhrudel' [11], a calculation is given of the trajectory of electrons in the high vacuum of a Penning tube. The calculation contains undetermined constants, because it was carried out for an electron which, in one way or another, had fallen into the plane of the anode at $t = 0$. If ionization of the gas is neglected, for an electron emitted by the cathode situated at a point on the tube axis, the calculation is simplified considerably, and its results may be compared with the experimental data.

Figure 1 indicates the coordinate axes and notation needed for the calculation. A homogeneous magnetic field is directed along the z axis, and for an axially symmetrical electric field, it is known that the potential

distribution in cylindrical coordinates is determined by the expression

$$U(r, z) = \sum_{n=0}^{\infty} (-1)^n \frac{U^{(2n)}(z)}{(n!)^2} \left(\frac{r}{2}\right)^{2n}, \quad (1)$$

where $U(z)$ is the potential distribution on the axis; $U^{(2n)}(z)$ is the $2n$ -th order derivative of $U(z)$. If for $U(z)$ we take the expression proposed by Smirnitskaya and Reikhrudel' [11], series (1) reduces to three terms

$$U(r, z) = U_0 + \frac{U_0}{2d^2} r^2 - \frac{U_0}{d^2} z^2, \quad (2)$$

where U_0 is the potential at the center of the anode ring.

With such a distribution of potential in the interelectrode space, simple transformations of the equation of motion of an electron moving away from the point with coordinates $(-d, 0)$ leads to equations

$$\ddot{z} + \frac{2eU_0}{md^2} z = 0, \quad (3)$$

$$\Theta = \frac{eH}{2mC}, \quad (4)$$

$$\ddot{r} + \left[\left(\frac{eH}{2mC} \right)^2 - \frac{eU_0}{md^2} \right] r = 0. \quad (5)$$

As is well-known, Equation (5) has three solutions: $r = A \operatorname{sh}(\omega t + \alpha)$ at $H < H_C$, $r = Bt + C$ at $H = H_C$ and $r = D \sin(\omega t + \beta)$ at $H > H_C$ where H_C is the critical value of the magnetic field determined from the condition

$$\frac{eH_C}{2mC} = \left(\frac{eU_0}{md^2} \right)^{1/2}. \quad (6)$$

Thus, for a system of electrons in the tube and a homogeneous magnetic field, an electron emitted from the cathode performs oscillations along the z axis, rotates around the z axis, and moves aperiodically along the r axis, if $H \leq H_C$; or performs oscillations along the r axis, if $H > H_C$.

CONDITION FOR EMERGENCE OF ELECTRON CURRENT

From the results of our measurements, curves were plotted of the variation of collector

current I_z as a function of magnetic field strength H for different anode voltages U_a and different interelectrode distances d . For the current measurements, we adopted measurements on the limit of secondary emission from the collector surface, which arise from contamination of the electrode during operation of the tube. In all these curves there is a pronounced maximum in the electron current region. One of such curves is given in Figure 2 for the case $d = 15$ mm, $U_a = 440$ v, $P = 4.4 \cdot 10^{-5}$ mm Hg. On the curve, above the H axis, electron current is plotted; below it — ion current.

For a given d to each anode voltage U_a corresponds a value of H , at which the electron current at the collector reaches a maximum. Such values of U_a and H for $d = 15$ mm are given in the first two columns of the table. In the third column are indicated the critical values of magnetic field strength, computed from Equations (2) and (6) at the condition $d = R$, $U(r, z) = U_a$ when $z = 0$ and $r = R$ (radius of the anode ring in the tube is $R = 15$ mm). It is apparent from the table that the values of H and H_c are very close.

Consequently, one may assume that the condition for emergence of electron current in the collector circuit is the equality $H = H_c$. A certain range of values of H , in which electron current exists, is obviously caused by a nonideal system of electrodes.

At the condition $H = H_c$, according to the solution of Equation (5), an electron which has been emitted from the cathode describes a conical spiral in the interelectrode space. The radius of the spiral, which increases with time, remains very small, because the constant B in the solution of Equation (5) is a radial component of the initial electron velocity, which is very small due to the uniformity of the electric field at the cathode. So, at $H = H_c$ the electron beam narrows down and the electron current density at the tube axis increases strongly. This is the condition at which electron current flows at the collector of a Penning tube.

3. MEASUREMENT OF ELECTRON ENERGY

The simplest explanation of the existence of electron current in the collector circuit would be the following: electrons at the cathode have a Maxwellian velocity distribution, corresponding to the cathode temperature, and a mean energy of the order 0.3 - 0.4 ev. As a consequence of this energy, electron current flows in the collector circuit. But the simplest measurements showed that this is not so.

We used a probe as the collector, and by applying to it a retarding potential relative to the cathode, we measured the electron current at the collector. Figure 3 gives the current at the collector I_z as a function of retarding potential U_z (Curve 1) for $U_a = 440$ v, $H = 50$ oe, $p = 15$ mm and $P = 2(10)^{-5}$ mm Hg. Curve 2 in this same figure corresponds to a pure electron current at the collector and is obtained by introducing a correction for the ion current, just as is usually done in a treatment of probe characteristics.

Figure 4 gives the logarithm of this current as a function of retarding potential. This curve contains a clearly expressed rectilinear section, which may be interpreted as due to the existence of a Maxwellian electron velocity distribution. From the slope of this rectilinear section, the electron temperature was found, which for the case depicted in Figure 3, was equal to 253,000° K which corresponds to a mean electron energy of 33 ev.

This value of electron temperature may be regarded as quite correct because Bohm and others [12] showed that the method of determining electron temperature from probe

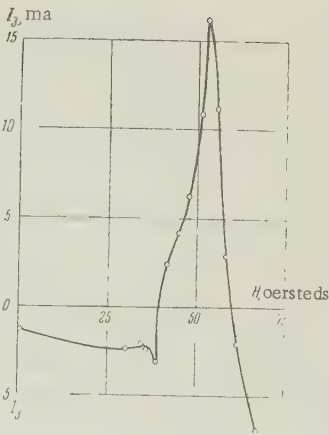


Figure 2

U_a , v	H , oersteds	H_c , oersteds
440	52.5	54.4
480	55.5	56.8
520	57.5	59.0
560	60.0	61.3
600	61.5	63.5

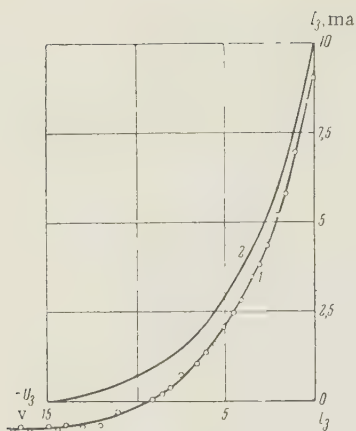


Figure 3

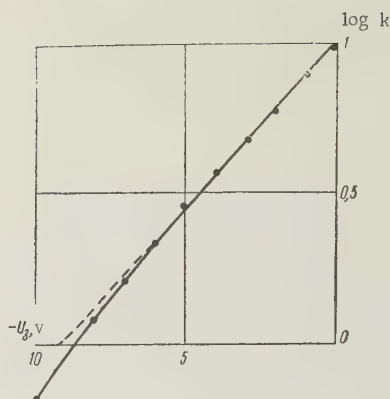


Figure 4

characteristics remains valid even in the presence of a magnetic field.

So, the mean electron energy at the collector surface is 10 times larger than at the cathode surface. Obviously, when $H = H_C$ electrons somewhere in the stream acquire additional energy which ensures their progress to the circuit of an electrode with negative potential. The gain by electron streams of additional energy in a magnetic field has long been known. Electrons of a high temperature up to 10^6 °K were even found by Langmuir [13] in a gas discharge. Later Vigdorchik [14] and after him Linder [15] discovered electrons of an anomalously high energy in a magnetron. This effect occurs also in other devices where magnetic focusing is used. Up to the present time, however no complete theory of this effect exists. Its interpretation in the papers of many researchers [16 - 20] and at present is a subject of discussion. In this light the investigation of anomalously high electron energies in Penning tubes is of theoretical interest. In addition, apparently, the presence of an electron current in the calibration of ionization gauges should be kept in mind.

CONCLUSIONS

It was found that at a given anode voltage, there exists a value of magnetic field intensity at which electron current instead of ion current flows in the collector circuit of a penning tube.

This phenomenon occurs when $H = H_C$, where H_C is the critical value of the magnetic field intensity, which gives rise to electron oscillations in planes perpendicular to the axis.

It was shown that the mean electron energy at the collector is approximately 10 times larger than at the cathode.

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MODIFIED FOUR-TERMINAL NETWORK METHOD FOR THE DETERMINATION OF SEMICONDUCTOR DIODE CONTACT IMPEDANCE AT SUPERHIGH FREQUENCIES

Yu. F. Sokolov

A method is proposed for the determination of complex socket-contact impedances up to frequencies of ~9400 Mc with any design of the diode head.

INTRODUCTION

Methods of measurement of the contact impedances of semiconductor diodes, based on a determination of the standing wave pattern (SWR and phase) in a line terminated by a diode, are different variations of the four-terminal network method [1]. The essence of this method consists of the following. If the diode socket with a contact lead to the diode head and with a line length up to a certain zero reference plane l is represented in the form of a linear four-terminal network¹, the following relation holds

$$z = \frac{a\zeta + 1}{b\zeta + c}, \quad (1)$$

where ζ is the impedance in the plane l of the line; z is the contact impedance; ζ and z are the input and output impedances of the four-terminal network, respectively; a , b and c are subject to a determination of the network constants.

The functional relation of the form (1) is determined uniquely, if three correspondences are given $z_i \rightarrow \zeta_i$, i.e., three values of z and three values of ζ such that if $z = z_i$, $\zeta = \zeta_i$ ($i = 1, 2, 3$) [2]. From this it follows that the network constants may be obtained, by determining experimentally the three correspondences $z_i \rightarrow \zeta_i$. Usually they are [1] where z_a

$$\begin{aligned} z = 0 &\rightarrow \zeta = \zeta_0, \\ z = \infty &\rightarrow \zeta = \zeta_\infty, \\ z = z_a &\rightarrow \zeta = \zeta_a, \end{aligned} \quad (2)$$

¹The four-terminal network includes transforming devices between the diode head and plane l , if available.

is a certain known contact impedance; ζ_0 , ζ_∞ and ζ_a are the impedances in plane 1, corresponding to contact impedances 0 , ∞ and z_a .

After the network constants are determined, Equation (1) can be used to determine z from the measured value of ζ .

In [3], a version of the four-terminal network method (method of input impedances) is described, wherein the zero reference plane is taken as the contact plane. To determine z from the measured value ζ the impedance in the contact plane is represented by the equivalent circuit of Figure 3, where C_S is the socket capacitance; L_K is the inductance of the contact head. Such a concept is based on the assumption that the diode head does not give additional reactance.² The equation of the four-terminal network, in this case, has the form

$$z = \frac{-(1 - \omega^2 L_K C_S) \zeta + j \omega L_K}{j \omega C_S \zeta - 1} \quad (3)$$

The values of C_S and L_K are determined from experiments in the open-circuit condition ($z = \infty \rightarrow \zeta = 1/j\omega C_S$) and the short-circuit condition ($z = 0 \rightarrow \zeta = j\omega L_K / (1 - \omega^2 L_K C_S)$).

The principal disadvantage of these methods is the necessity of using different sockets to determine correspondences (2) or C_S and L_K . This leads to an appreciable error in the determination of z , because the sockets are not identical in their parameters [1], and this means that the coefficients of a four-terminal network (or C_S and L_K) do not remain the same during the measurements. Errors due to the dispersion of the socket parameters increase sharply with frequency. In the short wavelength part of the microwave region, because of the large errors, these methods become inapplicable.

Investigations of the reactive properties of the socket show that not all the constructional elements have the same influence on its parameters [1]. If the experiments at the open-circuit condition, which characterize the reactive properties of the socket without a contact head, give good agreement of results in the case of measurements with different sockets, then experiments at the short-circuit condition, which characterize the properties of the contact wires, lead to appreciable dispersion for different sockets.

It follows from the foregoing that the creation of a method of measurement of the contact impedances of semiconductor diodes in the short-wavelength part of the microwave region is possible only if we exclude measurements with different contact wires or if the wire is not connected to the network.

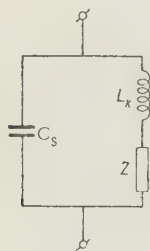


Figure 1

In [1], a method is described in which the same contact wire is used in all the experiments. This method, however, is very cumbersome, does not allow repeated measurements, and most important of all, it excludes the investigations over a wide frequency range.

In this paper, we describe a version of the four-terminal network, which is free of the drawbacks of the methods mentioned above. It makes it possible to measure the contact impedances of a socket over a wide frequency range; it does not require the use of the same contact wire for all the experiments, and it does not

impose a limitation on the design of the diode head.

1. NEW METHOD OF MEASURING CONTACT IMPEDANCE

The first step of this method is a redefinition of a four-terminal network. We will assume that a four-terminal network consists of a line section up to the zero reference plane 1, of a diode head and socket without a contact wire. The four-terminal network defined in this manner is purely reactive and does not change in the case of measurements

²The assumption imposes great limitations on the design of a diode head. Thus, for example in the waveguide version, because of the existence of reactance in the head, the input impedance method is inapplicable.

with different sockets. The input impedance z' will now be added up from the contact impedance z and the reactive impedance $j\omega L_k$ of the contact wire connected in series with it

$$z' = z + j\omega L_k. \quad (4)$$

The equation of the four-terminal network in this case has the form

$$z' = \frac{a'\xi + 1}{b'\xi + C'}. \quad (1a)$$

We will determine the plane l , by requiring that the following correspondence hold:

$$z' = \infty \rightarrow \xi = 0. \quad (5)$$

It follows from (5) that the zero reference plane is a nodal plane of the standing wave in the case of an experiment at the open-circuit condition.

Substitution of correspondence (5) into (1a) leads to

$$z' = A + By, \quad (6)$$

where $A = a'/b'$; $B = 1/b'$ and $y = 1/\xi$ is the conductivity in the plane l .

In the general case A and B are complex coefficients. Let

$$A = \alpha_1 + j\alpha_2, \quad (7)$$

$$B = \beta_1 + j\beta_2.$$

Also let

$$z' = r + j(x + \omega L_k), \quad (8)$$

$$y = g + jb, \quad (9)$$

where r and x , respectively, are the real and imaginary parts of the contact impedance; g and b are the real and imaginary parts of conductivity and the zero reference.

Substituting (7), (8) and (9) into (6) and separating the real and imaginary parts, we obtain

$$r = \alpha_1 + \beta_1 g - \beta_2 b, \quad (10)$$

$$x = \alpha_2 + \beta_2 g + \beta_1 b - \omega L_k. \quad (11)$$

Equations (10) and (11) are valid for arbitrary r and x . Let $r = 0$, i.e., the contact impedance is purely reactive. Since the four-terminal network is reactive, g also equals zero, and it follows from (10) that

$$\alpha_1 - \beta_2 b = 0. \quad (10a)$$

Since x , and consequently, also b are arbitrary, (10a) holds only if

$$\alpha_1 = \beta_2 \equiv 0. \quad (12)$$

Equations (10) and (11) take the following forms (indices of α and β are omitted), when we take into account (12)

$$r = \beta g, \quad (13)$$

$$x = \beta b + (\alpha - \omega L_k). \quad (14)$$

So, if the zero reference plane is determined by relation (5), Re depends only on $Re y$, and $Im z$ only on $Im y$.

In order to use Equations (13) and (14) to determine r and x from the measured values of g and b , one must be able to find the coefficients β and $(\alpha - \omega L_k)$.

Since β depends only on the properties of the four-terminal network and thus remains constant during measurements with different diodes, it can be determined by measuring g when connected to a diode line with a previously specified value of the inphase component of the contact impedance. Such a diode can be one with an ohmic contact, which has a

frequency-independent impedance R . If the corresponding conductance value is $g = gR$,

$$\beta = \frac{R}{g_{lt}}. \quad (15)$$

To eliminate possible errors of measurement, it is expedient to determine β for several diodes with ohmic contact and then average the resulting values.

When the equivalent circuit of Figure 1 is valid, β can be assumed with good accuracy to be equal in magnitude to the wave impedance of the line W (see Appendix).

The error-free values $(\alpha - \omega L_k)$, connected with the dispersion of L_k , must be determined for the investigated diode. This can be done in the following manner.

It is known [4] that z the impedance of the rectifying contact as a function of constant positive bias current I is such that

$$\lim_{i \rightarrow \infty} z(i) = r_s, \quad (16)$$

where r_s is the impedance of a crystal, or

$$\lim_{i \rightarrow \infty} x(i) = 0. \quad (17)$$

Hence, it follows that from extrapolation of the function $b(i)$ to a large current, one can determine $(\alpha - \omega L_k)$. Indeed, from (14) and (17) we have

$$\alpha - \omega L_k = -\beta b_\infty, \quad (18)$$

where

$$b_\infty = \lim_{i \rightarrow \infty} b(i).$$

Substituting (18) into (14), we obtain

$$x = -\beta(b_\infty - b). \quad (19)$$

In practice, the determination of b_∞ is more conveniently done from extrapolation of y , and not b . It follows from (13) and (14), that the function $y(i)$ in the complex plane (g, jb) is a duplication of the function $z(i)$ in the complex plane (r, jx) except for a scale factor and a shift along the imaginary axis. The latter function at positive i is described by the equation of a circle or a straight line [4]. If we construct the experimental relation $y(i)$ on the (g, jb) plane (see Figure 2) and extend it till it intersects the straight line $\text{Re } y = r_s/\beta$, then according to (13) (16), (17), (18) and (19), the ordinate of the point of intersection equals b_∞ .

2. EXPERIMENT

One of the basic premises of the proposed method is the assumption of the invariability of the four-terminal network upon changing sockets. The accuracy with which this assumption is fulfilled determines also the accuracy of the method.³ The experimental reproducibility characteristic of a four-terminal network upon changing sockets is the preservation of the position of the zero reference plane. It is natural therefore to take as a measure of the deviation of the four-terminal network from the ideal value of the RMS deviation $(\delta l)^2$ of the position of this plane.

The experimental determination of $(\delta l)^2$ was carried out over the range 500 - 9400 Mc. The measuring apparatus were analogous to those in [1]. The position of the zero reference plane was measured with alternate connection of sockets without contact wires into the diode head. The results are given in Table 1. The value of $(\delta l)^2$ is expressed in units of the phase angle. In this same table are given values of the corresponding relative errors of

³Other factors determining the accuracy of measurements of z (apparatus errors in determinations of the SWR and phase), do not characterize the method and therefore are not considered.

the determination of g and b for typical diodes. As may be seen from Table 1, the assumption of invariance for the four-terminal network for a change of diodes is justified with good accuracy up to the frequency ~ 9400 Mc.

For practical realization of the method expounded in the preceding paragraph, one must have diodes with ohmic and frequency-independent contact impedances. In addition, the magnitudes of the impedance should lie within reasonable limits (10-100 ohm), so that g can be measured with sufficient accuracy. The latter condition is fulfilled, if we choose germanium as the material for preparation of the ohmic resistance and make the contacts of a sufficiently small area. An ohmic contact can be obtained by means of fusion of Sn with an addition of Sb in n-type Ge or In with an addition of Ga in p-type Ge. The wafer thickness d and resistivity of the material ρ are selected from the condition of frequency independence of the contact impedance, which have the form⁴

$$\omega \frac{\epsilon \rho}{4\pi} \ll 1, \quad \Delta \approx c \sqrt{\frac{\rho}{2\pi\omega}} \gg d, \quad (20)$$

where ϵ is the dielectric constant; Δ is the surface layer depth; c is the velocity of light.

Table 1

$f, \text{ Mc}$	$\left(\frac{2\pi l}{\lambda}\right)^2$	$\frac{\delta g}{g}$	$\frac{\delta b}{b}$
500	0.003	—	—
1000	0.006	<0.04	<0.02
3200	0.007	<0.04	<0.02
9400	0.012	<0.07	<0.04

Table 2

$f, \text{ Mc}$	β	w
500	74 ± 3	75
1000	75 ± 1	75
3200	55 ± 1	50
9400	23 ± 1	—

The first inequality (20) determines the range of values of ρ for which the bias current can be neglected; in other words it determines the shunting action of the self-capacitance. The second inequality determines the values of ρ and d , at which the surface effect can be neglected.

Conditions (20) lead to the following double inequality for ρ :

$$\frac{2\pi\omega d^2}{c^2} \ll \rho \ll \frac{4\pi}{\epsilon\omega}. \quad (21)$$

In our case the crystal thickness d is chosen to be 200 m, and the maximum frequency $\omega \approx 6(10) \text{ sec}^{-1}$. In addition from (21) we obtain

$$0.15 \ll \rho \ll 12.$$

According to (21a) ρ was chosen equal to 1 ohm-cm.

(21a)

The ohmic contacts were prepared by melting drippings of In + 1% Ga with a diameter ~ 100 m in p-type Ge.⁵ The alloyed ohmic contact obtained in such a manner was fitted in the socket, after which the contact wire was inserted. The contact impedances of such diodes were within the limits from 8 to 30 ohm.

Table 2 gives the average values of β , determined experimentally with the help of these diodes. In addition, in the table are given the values of the wave impedances of the corresponding lines. It is easy to see that at frequencies 500, 1000 and 3200 Mc, when the equivalent circuit of Figure 1 is valid [5], there is satisfactory agreement between the values

⁴Since the contact is ohmic and, consequently, is noninjecting, there are no processes in it, connected with nonequilibrium carriers, which lead to frequency variation of the impedance.

⁵The choice of type of material is determined purely by technological considerations.

β and the wave impedance.⁶ This can be regarded as good verification of the correctness of the proposed method of determination of β with the help of diodes with an ohmic contact.

The proposed method was used for measurements of the contact impedances of germanium diodes [6]. The measurements were carried out at frequencies 1000, 3200 and 9400 Mc. The results are in rather good agreement with data obtained by the input impedance method at frequencies 1000 and 3200 Mc. Results of measurements at frequency 9400 Mc show that the values of capacitance and contact impedance in the rectifying direction are practically the same as for measurements at the frequency 3200 Mc. Direct comparison of the methods at the frequency 9400 Mc was not carried out, since the existing methods do not make it possible to measure, at this frequency, the contact impedances in the socket.

In conclusion, I have the pleasant duty of expressing my gratitude to E.A. Panteleimonova for preparing diodes with ohmic contact.

APPENDIX

In the derivation of Equations (13) and (14), no assumption was made regarding the possibility of representing the four-terminal network by a concrete equivalent circuit. Concretion of the four-terminal network, naturally, limits the domain of applicability of the method, but as shown below, at the same time, the procedure for the determination of β is considerably simplified.

We assume that the diode impedance in the contact plane can be represented by the equivalent circuit of Figure 1. In this case

$$z_d = \frac{1}{j\omega C_s + \frac{1}{z'}}, \quad (I)$$

where z_d is the diode impedance in the contact plane.

The input impedance of the line, terminated by impedance z_d at a distance L from it equals

$$\xi(L) = W \frac{z_d + jW \tan \gamma L}{W + jz_d \tan \gamma L}, \quad (II)$$

where $\gamma = 2\pi/\lambda$ is the wavenumber; W is the line wave impedance.

If one determines the zero reference plane by relation (5), it follows from (I) and (II) that

$$\frac{1}{\omega C_s} = -W \tan \gamma l, \quad (III)$$

where l is the distance from the contact plane to the zero reference plane.

Substituting (III) and (I) into (II) and making a series transformation, we obtain

$$r = \frac{W}{1 + \omega^2 W^2 C_s^2} g, \quad (IV)$$

$$x = \frac{W}{1 + \omega^2 W^2 C_s^2} b + \left(\frac{\omega W^2 C_s}{1 + \omega^2 W^2 C_s^2} - \omega L_K \right), \quad (V)$$

where g and b are the given conductivities in the zero reference plane.

It is easy to see that if one designates

$$\beta = \frac{W}{1 + \omega^2 W^2 C_s^2}, \quad (VI)$$

$$\alpha = \frac{\omega W^2 C_s}{1 + \omega^2 W^2 C_s^2}, \quad (VII)$$

⁶ At the frequency 9400 Mc, it is possible to represent the diode head with the diode, by the equivalent circuit of Figure 1.

then Equations (IV) and (V) agree respectively with (13) and (14).

Usually C_s is such that

$$\omega^2 W^2 C_s^2 \ll 1, \quad (\text{VIII})$$

and from (VI) we obtain

$$\beta \simeq W. \quad (\text{IX})$$

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STUB DELAY STRUCTURE FOR TRAVELING-WAVE PARAMAGNETIC AMPLIFIER OF CENTIMETER WAVELENGTH

E.G. Solovyev and E.K. Karlova

A new construction of a high frequency channel of a traveling wave paramagnetic amplifier which utilizes a stub delay structure is described, and results of experimental investigation are presented.

1. PRINCIPAL CONSIDERATIONS OF THE CHOICE OF GEOMETRIC DIMENSIONS OF THE DELAY STRUCTURE

The system described in the work [1] was used as the basis on which was designed the delay structure for the traveling-wave paramagnetic amplifier. A row of periodically spaced metallic stubs are tightened against one of the narrow walls of a waveguide. There is a space between the other wall of the waveguide and the butt ends of the stubs. Such a periodic structure has the property of "slowing" electromagnetic waves.

On the basis of analysis of the main properties of periodic structure one may write down the formula which permits one to estimate the magnitude of the minimum slowing of the group velocity in the first bandwidth and at the same time to see how the geometric dimensions of the periodic structure must be changed in order to obtain the desired characteristics of the delay structure (delay, operating band).

A typical dispersion curve of such delay structures is shown in Figure 1 with the wavelength

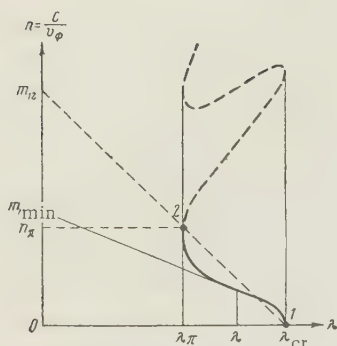


Figure 1. Dispersion curve.

as ordinate vs. the ratio of the speed of light to the phase velocity of the wave, (n). One of the interesting properties of this graph is the fact that the tangent to the dispersion curve crosses the ordinate axis at a point whose ordinate gives the value of the retardation of the group velocity (m).

Point 1 on the dispersion curve corresponds to the long wavelength boundary of the bandwidth (transverse resonance).

The straight line which crosses points 1 and 2 always gives the value m_{12} which is greater in value than the minimum value $m_{\min}$ in the bandwidth of the system.

Once the values of λ_{CR} , λ_{π} and n_{π} are known one may simply determine m_{12} (see Figure 1):

$$m_{12} = n_{\pi} \frac{\lambda_{CR}}{\lambda_{CR} - \lambda_{\pi}}. \quad (1)$$

The minimum slowing of the group velocity in the middle portion of the bandwidth is smaller than m_{12} by several times. Hence, formula (1) may be recommended for rough calculations.

The unknown magnitudes λ_{π} and n_{π} that enter into formula (1) may be determined with the help of the expressions:

$$\lambda_{\pi} \simeq 4l; \quad n_{\pi} = \frac{\lambda_{\pi}}{2D}, \quad (2)$$

where l is the height of the stub; D is the period of the structure; λ_{CR} is essentially determined from the geometrical dimensions of the cross section of the delay structure. For initial calculations one may assume that the value of λ_{CR} coincides with the critical wavelength of a P-mode waveguide with the same cross-sectional area as the cross-sectional area of the stub delay structure at the position at which the stub is connected. The graphs of the work [2] make it possible to determine rather easily this magnitude (one may use the formulas in the indicated article in more accurate calculations).

It follows from formula (1) that in order to obtain large retarding of the group velocity one must narrow the bandwidth and decrease the period of the periodic structure.

On approaching the limits of the bandwidth, the slowing of the group velocity increases sharply and tends to infinity at the boundaries. However, portions of the bandwidth near λ_{CR} and λ_{π} may not be considered as operable, since, as it is shown below, in these portions of the band the lengthwise attenuation of the system increases sharply and the matching with the outside loops worsens.

2. PECULIARITIES OF CONSTRUCTION OF THE DELAY SYSTEM

Photographs of a model of the high-frequency channel of a paramagnetic amplifier and the stub delay structure with rubies (pink and red) at the base of the stubs are shown in Figure 2. The system is different from the one described in [1] mainly in the use of a new wideband method of matching the stub of the delay structure and in a new method of bringing in the pumping signal.

The high-frequency matching loop is shown schematically on Figure 3. At the edges of the delay structure, the height of the stubs decreases slowly to zero, for a length of the order of one wavelength, and the side walls form a horn of such dimensions that the critical wavelength in each cross section is greater than the critical wavelength of the delay structure. Such a method of high-frequency matching guarantees a smooth transformation of the high frequency field of the delay structure into a field of type H_{10} in a rectangular waveguide.

The pumping signal is led in by a rectangular waveguide through the side wall in the center of the slowing structure from the side of the pink ruby in such a manner that the field vector E of the pumping is perpendicular to the side plane of the stub. In order to separate the channels of the operating signal and of the pumping signal, the fact is utilized

that the polarization planes of these oscillations are perpendicular to each other. By decreasing the narrow wall of the main waveguide to such a magnitude that the channel will be a limiting waveguide at the pumping frequency, one may obtain the desired degree of separation between the two channels. The main signal cannot enter into the pumping channel, since the waveguide of the pumping channel is also limiting.

To augment the construction of a cross section of small dimensions with the aim of placing it in a Dewar vessel the output waveguide and the pumping waveguide are placed along the axis of the structure, while their articulation with the corresponding openings is made possible by means of smooth bends (see Figure 2).

3. MAIN CHARACTERISTICS OF THE PROTOTYPE

In the text and in the drawings, all dimensions and wavelengths are given in relative units (with respect to the average wavelength of the bandwidth of a periodic structure). The figures for the slowing of the group velocity are given for $\lambda = \lambda_{cr}$.

In Figure 4 a family of experimental dispersion characteristics of the investigated stub slowing structure is presented. The curves give a representation of the

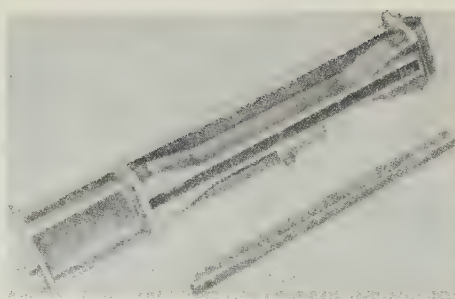


Figure 2. High-frequency channel and stub of delay structure.

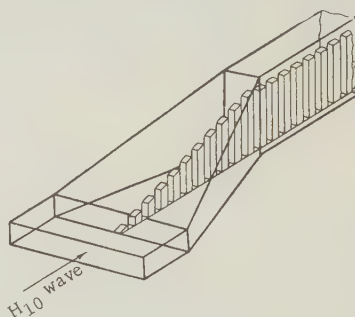


Figure 3. High-frequency matching loop.

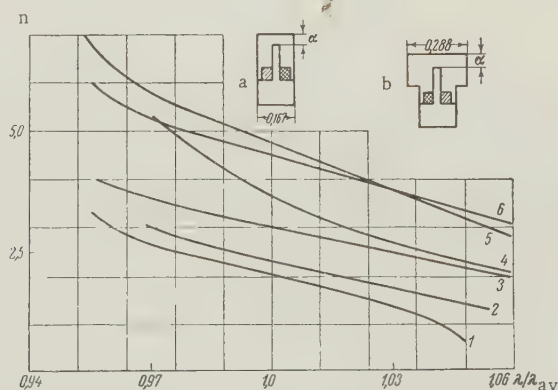


Figure 4. Family of experimental dispersion characteristics of a stub structure with height 0.222.

Curves 1 - 5 refer to the system having a cross section shown in Figure 4a; Curve 6 refers to system shown in Figure 4b. Curve 1 is the case where $\alpha = 0.065$, $m = 23$; 2 - $\alpha = 0.045$, $m = 21$; 3 - $\alpha = 0.030$, $m = 20$; 4 - $\alpha = 0.065$ with rubies, $m = 45$; 5 - $\alpha = 0.030$ with rubies, $m = 38$; 6 - $\alpha = 0.030$ with rubies, $m = 28$

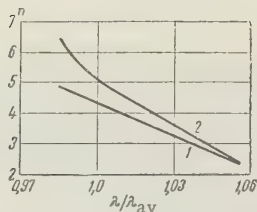


Figure 5. Experimental characteristics of a stub structure with height 0.227:

1 - $\alpha = 0.065$, $m = 38$; 2 - $\alpha = 0.065$ with rubies, $m = 55$.

0.033, space between stubs 0.017, stub thickness 0.030.

On Figure 5. The analogous experimental curves for a stub slowing structure which is only distinguished by a larger stub height (0.227 instead of 0.222) are presented.

As follows from the curves, the increase in the stub height for the same values of the other dimensions leads to an increase in the slowing of the group velocity and to a certain shift of the band toward the long wavelength range.

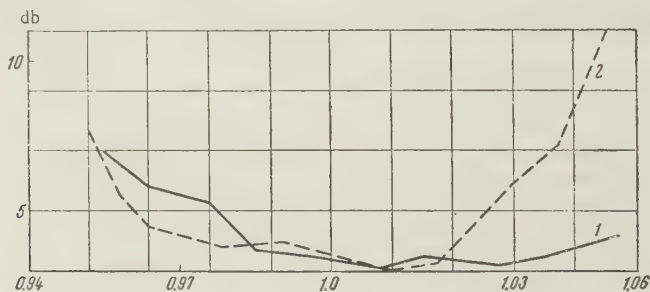


Figure 6. Attenuation curves of the prototype:

1 - $\alpha = 0.030$; 2 - $\alpha = 0.045$.

Curves of attenuation of the entire prototype (including all losses at the input and output) are given in Figure 6, for a delay structure with stub height 0.222. As follows from the curves, the minimum losses in the center of the bandwidth are in the order of 3 - 4 db at 20°C.

The SWR curves of the main channel have the same character of the change in the wavelength band as the attenuation curves. The SWR does not go above 2 in almost the entire bandwidth, except for the edges. Upon the arrival near the edges of the bandwidth a sharp increase in the SWR is noted.

CONCLUSIONS

1. The described construction of a high frequency channel paramagnetic amplifier with the utilization of a stub slowing structure may be recommended for use in the centimeter and millimeter wavelengths.

2. Values of the slowing of the group velocity were obtained in the order of 50 - 100 times in a band of the order of 10% for an attenuation of the entire channel at the center of the bandwidth in the order of 3 - 4 db.

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SATURATION AND RECOVERY TIME OF PARAMAGNETIC AMPLIFIERS

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The dependence of the amplification coefficients of paramagnetic amplifiers of the resonator type and of the traveling wave on the power of the input signal is determined; the recovery time is calculated and a possible way of improving these parameters is indicated.

Upon the arrival of a powerful signal in an amplifier, the magnitude of the amplification falls sharply because of the saturation effect. Upon removal of this signal, the amplification attains its nominal value only after a certain time. It is interesting to determine the dependence of the magnitude of the coefficient of amplification on the signal power, to find the dependence of the recovery time on the amplification coefficient and, finally, to indicate certain ways of shortening the recovery time.

We will examine three-level amplifiers with auxiliary emission [1, 2]. In the three-level system let the signal shift be between levels 1 and 2, and the auxiliary emission between levels 1 and 3. Upon action of the saturation effect on the signal transfer, the population difference $N_2 - N_1$ changes, where this dependence may be given in the form

$$z = \frac{N_3 - N_1}{N} \frac{z_0}{1 + \frac{3}{2} W_{12} T_1}, \quad (1)$$

where N_i is the number of particles in the i -th level; $N = \sum_{i=1}^3 N_i$ is the entire number of particles; $W_{12} = \frac{|\mu_{12}|^2}{\hbar^2} H_C^2 T_2$ is the probability of the transfer in a unit time upon the influence of the signal; z_0 is the relative difference of the populations when $W_{12} \rightarrow 0$; T_1 is the spin-lattice relaxation time; μ_{12} is the matrix element which corresponds to a signal transfer; T_2 is the spin-relaxation time; H_C is the magnitude of the magnetic field of the signal. The magnitudes z_0 and T_1 may be expressed in terms of the relaxation probabilities

$$z_0 = \frac{w_{32} - w_{23} - (w_{21} - w_{12})}{w_{12} + 2w_{21} + w_{32} + 2w_{33}}, \quad (2)$$

$$T_1 = \frac{2}{w_{12} + 2w_{21} + w_{32} + 2w_{33}}, \quad (3)$$

where

$$w_{ik} = w_{ki} e^{\hbar \nu_{ik} / kT}; \quad \nu_{ik} = \frac{E_i - E_k}{\hbar}.$$

It follows from formula (1) that for a large signal the magnitude of z decreases, and that consequently the magnitude of the amplification also decreases. Let us examine this effect for paramagnetic amplifiers of the resonator type, as well as for traveling wave paramagnetic amplifiers.

For resonator paramagnetic amplifiers of the reflection type, the derivation of the coefficient of voltage amplification K from the bandwidth Δf is given by the relation

$$(K - 1) \Delta f = 2\nu_{12} \left(\frac{1}{|Q_M|} - \frac{1}{Q_0} \right) = A. \quad (4)$$

Then, assuming that the unloaded quality factor of the resonator Q_0 is considerably greater than the magnetic quality factor $|Q_M|$, we will obtain

$$K = \frac{|Q_M| + Q_{\text{conn}}}{|Q_M| - Q_{\text{conn}}} \quad (5)$$

Where Q_{conn} is the quality factor of the connection conditioned by losses in the line. Since the magnetic quality factor is inversely proportional to z ,

$$|Q_M| = \frac{a}{z}, \quad (6)$$

then, in accordance with (1) and the connection between the maximum coefficient of amplification K_0 and the value z_0 , it is not difficult to obtain

$$K = \frac{K_0 + \frac{3}{4}(K_0 + 1)W_{12}T_1}{1 + \frac{3}{4}(K_0 + 1)W_{12}T_1}. \quad (7)$$

It is seen from (7) that upon an increase in the signal intensity, i.e., when $W_{12}T_1 \rightarrow \infty$, $K \rightarrow 1$. It is necessary for an accurate determination of the dependence of amplification on the signal power to know the distribution of high-frequency fields in the resonator. However, it is sufficient to make an approximation connecting the signal power p_{in} with the quantity H_c^2 , which appears in Equation (1), using the loaded quality factor Q for an amplification K :

$$H_c^2 = \frac{2Q}{\kappa_{12}} \frac{\kappa}{v} p_{in}, \quad (8)$$

Where κ is the filling factor; v is the volume of the operating substance.

Since

$$Q = \frac{K+1}{2} Q_{gr} = (K+1) \frac{K_0-1}{K_0+1} \frac{v_{12}}{A}, \quad (9)$$

then one may obtain from (1), (7) and (8) the relation

$$K = \frac{K_0 + (K+1)(K_0-1)sp_{in}}{1 + (K+1)(K_0-1)sp_{in}}, \quad (10)$$

where s is introduced for the saturation of the resonator paramagnetic amplifier:

$$s = \frac{3}{4} \kappa \frac{|\mu_{12}|^2 T_2 T_1}{\hbar^2 v A}. \quad (11)$$

The solution of Equation (10) finally results in

$$K = \frac{\sqrt{1 + 4K_0(K_0-1)sp_{in} + 4(K_0-1)^2 s^2 p_{in}^2} - 1}{2(K_0-1)sp_{in}}. \quad (12)$$

The obtained relations show that for the given initial amplification in the amplifier of any kind of construction, an improvement in the dynamic characteristics may only be obtained by means of a decrease in the relaxation time. In Figure 1, graphs of the dependence of the amplification of a resonator paramagnetic amplifier on the input signal power (solid lines) are presented.

The recovery time τ_R after removal of the fully saturating signal to a value $K < K_0$ may be calculated from Equations (5) and (6), if one assumes that the recovery of the inversion obeys the law

$$z = z_0 (1 - e^{-t/T_1}). \quad (13)$$

Then

$$e^{-\tau_R/T_1} = \frac{2(K_0 - K)}{(K_0 - 1)(K + 1)}. \quad (14)$$

If we agree that the recovery time up to a level $K = 0.9 K_0$ interests us (i.e., up to an amplification 1 db less than the maximum) then

$$\tau_r = T_1 \ln \frac{(0.9 K_0 + 1)(K_0 - 1)}{0.2 K_0}. \quad (15)$$

From the above it is seen that the recovery time is not only determined by the relaxation time T_1 , but also by the magnitude of K_0 . In Figure 2 the dependence of the ratio τ_R/T_1 , on the maximum amplification of the resonator paramagnetic amplifier is indicated by solid lines.

The expression for the power amplification factor of a traveling wave paramagnetic amplifier is easily obtained by generalizing the magnetic quality factor to the case of systems with traveling waves. The energy flow p , distributed along the system with a group velocity v_{gr} is related to $|Q_m|$ by the relation

$$\frac{dp}{dx} = \frac{2\pi v_{12} p}{v_{gr} |Q_M|}. \quad (16)$$

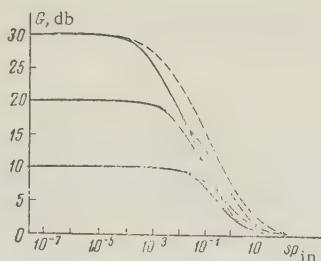


Figure 1

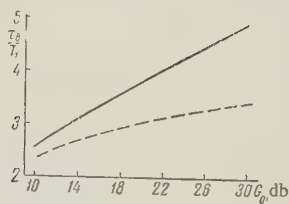


Figure 2

As in the previous case, $|Q_M|$ is inversely proportional to the inversion z , which in its turn is determined from Equation (1). An accurate calculation of $|Q_M|$ requires a specification of the type of oscillation and the field distribution in the traveling-wave system. However, one may make an approximation which connects the linear energy density in the examined system $p |v_{gr}|$ with H_c^2 :

$$H_c^2 = 4\pi \frac{\kappa}{\Omega} \frac{P}{v_{gr}}, \quad (17)$$

where κ is the fill factor; Ω is the surface of a cross section of the operating substance.

In accordance with Equations (17), (6) and (1), Equation (16) is written in the form

$$\frac{dp}{dx} = \frac{Ap}{1 + sp}, \quad (18)$$

where A is the amplification factor; s is the coefficient of saturation of the traveling-wave paramagnetic amplifier. As a direct calculation shows,

$$A = \frac{8\pi^2 \kappa n_1 \epsilon_0 |\mu_{12}|^2 T_2 v_{12}}{\hbar v_{gr}}, \quad (19)$$

$$s = \frac{6\pi \kappa |\mu_{12}|^2 T_2 T_1}{\hbar^2 v_{gr} \Omega}, \quad (20)$$

where n_1 is the nonlinear density of the particles.

Equation (18) is easily integrated:

$$p(x) = p_{in} e^{Al} e^{-s[p(x) - p_{in}]}, \quad (21)$$

Consequently, the amplification factor of a traveling-wave paramagnetic amplifier is

$$G \equiv \frac{p(l)}{p_{in}} = G_0 e^{-(G-1)sp_{in}}, \quad (22)$$

where $G_0 = e^{Al}$ is the coefficient of power amplification of the paramagnetic amplifier with a traveling wave of wavelength l for vanishingly small input signals.

In Figure 1 the dependences of the amplification of a traveling-wave paramagnetic amplifier on the input signal power are indicated by dotted curves. As is seen from the given graphs, for the same coefficient of saturation the amplification of the traveling-wave paramagnetic amplifier decreases with an increase in p_{in} , somewhat less sharply than in the case of a resonator paramagnetic amplifier.

During the determination of the recovery time of a traveling-wave paramagnetic amplifier, after removal of the saturating signal, it must be noted that in the recovery process the inversion varies in time according to (13). Then, in accordance with the fact

that $\ln G$ is proportional to z , we will obtain

$$e^{-\tau_R/T_1} = \frac{\ln G_0 - \ln G}{\ln G_0}. \quad (23)$$

If it is assumed that in the time τ_R the amplification will attain the level $G = 0.8 G_0$, i.e., will fail to reach the level of maximum amplification by 1 db, then

$$\tau_R = T_1 (\ln \ln G_0 + 1.51). \quad (24)$$

In this way, as in the case of the resonator paramagnetic amplifier, the recovery time is not only determined by the magnitude T_1 , but also by the value G_0 . It is seen from the graph that for the same T_1 , and G , the recovery time of a traveling-wave paramagnetic amplifier is smaller than in the case of a resonator paramagnetic amplifier.

It follows, from the considerations above, that improvement in the amplitude and relaxation characteristics of paramagnetic amplifiers must go hand in hand with a decrease in the relaxation time T_1 .

This decrease may be obtained by means of an increase in the operating temperature. The temperature dependence of the relaxation probabilities depends very much on the concentration of chromium in the corundum [3, 4] and may be made sufficiently large for operation above the temperature of helium. However, not only the recovery time is determined from relaxation probabilities. When they are increased the energy density of the auxiliary high-frequency field should increase, since the condition for saturation with auxiliary transition is written in the form

$$W_{13} = \frac{|\mu_{13}|^2}{h^2} \text{aux } T_2 \gg w_{1k} \simeq \frac{1}{T_1}, \quad (25)$$

where μ_{13} is the matrix element for the transition $1 \leftrightarrow 3$, H_{aux} is the voltage of the high-frequency magnetic field of auxiliary emission. In addition, the magnetic quality factor increases upon increase of the temperature.

One may also add to the paramagnetic substance paramagnetic additions. Thus, the desired effect can be obtained not by way of a decrease in all the relaxation probabilities, but only by the "hole" transition $2 \leftrightarrow 3$.

Certain advantages of an increase in the probability w_{23} were already described in the literature [5, 6]. It was shown that an increase in w_{23} increases the inversion. However, it also results in the possibility of decreasing the magnitude of T_1 .

Let us write down the expression for the number of particles for the examined three energy levels for $W_{12} = 0$:

$$\begin{aligned} \frac{dN_1}{dt} &= -N_1(w_{12} + w_{13}) + N_2w_{21} + N_3w_{31} + (N_3 - N_1)W_{13}, \\ \frac{dN_2}{dt} &= -N_2(w_{21} + w_{23}) + N_1w_{12} + N_3w_{32}, \\ \frac{dN_3}{dt} &= -N_3(w_{31} + w_{32}) + N_1w_{13} + N_2w_{23} - (N_3 - N_1)W_{13}. \end{aligned} \quad (26)$$

After substitution of the variables $N_2 - N_1 = zN$; $N_3 - N_1 = xN$ and $N_1 + N_2 + N_3 = N$ from relations (26), a second-order differential equation for the inversion z is obtained,

$$\frac{d^2z}{dt^2} - (b_1 + c) \frac{dz}{dt} + (b_1c - bc_1)z + ab_1 - a_1b = 0, \quad (27)$$

the general solution to which is of the form

$$z = Ae^{\alpha_1 t} + Be^{\alpha_2 t} + z_{\text{stat}}, \quad (28)$$

$$\alpha_{1,2} = \frac{b_1 + c}{2} \pm \sqrt{\frac{(b_1 + c)^2}{4} + bc_1 - b_1c}; \quad (29)$$

$$z_{\text{stat}} = \frac{ab_1 - a_1b}{bc_1 - b_1c}. \quad (30)$$

It must be noted that the relative difference in the populations between the auxiliary levels

$$x_{\text{stat}} = \frac{ac_1 - a_1c}{b_1c - bc_1}. \quad (31)$$

Not analyzing the relation in its general form, let us take advantage of the relation

$$\begin{aligned} w_{23} &\gg w_{13}, w_{12}, \\ W_{13} &\gg w_{13}, w_{12}. \end{aligned} \quad (32)$$

In this case the coefficients in Equations (27) - (31) are written in the following manner:

$$\begin{aligned} a &= -a_1 = \frac{w_{23} - w_{23}}{3}, & c_1 &= -c = \frac{w_{23} + 2w_{23}}{3}, \\ b &= \frac{2w_{23} + w_{23} - 3W_{13}}{3}, & b_1 &= -\frac{2w_{23} + w_{23} + 6W_{13}}{3}. \end{aligned} \quad (33)$$

Substituting the constants (33) into Equations (30) and (31), we conclude that for the realization of the inequalities (32), $x_{\text{stat}} \rightarrow 0$, and z_{stat} reaches the value

$$z_{\text{stat}} = (w_{32} - w_{23}) / (w_{32} + 2w_{23}) \simeq h\nu_{12} / 3kT.$$

This proves that when the first of the conditions (32) is obeyed, the maximum inversion is obtained and that the power of radiation necessary for saturation of the auxiliary transition does not depend on w_{23} .

Let us substitute the constants (33) into Equation (29) in order to determine the relaxation time of the magnetic quality factor. Assuming a small ratio $h\nu_{12}/kT$, we obtain

$$\alpha_{1,2} = -w_{23} - W_{13} \pm \sqrt{w_{23}^2 - w_{23}W_{13} + W_{13}^2}. \quad (34)$$

Here it is practical to examine two extreme specific cases:

$$1) w_{23} \gg W_{13}; \quad 2) w_{23} \ll W_{13}. \quad (35)$$

In each of these cases we see that the inversion z is described by Equation (13), i.e., has a single relaxation time T_1 , and not two, as follows from the general solution (28). If the first of conditions (35) is obeyed, then

$$T_1 = \frac{2}{3} \frac{1}{|W_{13}|}, \quad (36)$$

If, however, $W_{13} \gg w_{23}$ then

$$T_1 = \frac{2}{3} \frac{1}{w_{23}}. \quad (37)$$

The correlation (36) noticeably differs from Equation (25) in that instead of the sign "much greater than", the equality sign is used here. Thus, the condition of saturation of the auxiliary transition satisfies inequalities (32). If the relaxation time T_1 is given, then it is easy to determine the necessary energy density of the auxiliary emission

$$\text{aux} = \frac{\hbar^2}{|\mu_{13}|^2 T_2 T_1}. \quad (38)$$

At the same time the necessity of the auxiliary transition gives

$$\text{aux} \gg \frac{\hbar^2 w_{13}}{|\mu_{13}|^2 T_2}, \quad \frac{\hbar^2 w_{12}}{|\mu_{13}|^2 T_2}. \quad (39)$$

Consequently, when inequalities (32) and the first of conditions (35) are satisfied, the dynamic band and the recovery time in paramagnetic amplifiers will be determined by the power of auxiliary-emission sources. In certain cases it may be practical to utilize additional pulse generators for auxiliary emission.

In this way, the decrease in the time T_1 by way of an increase of only one relaxation probability (for a single transfer) allows us to obtain the maximum number of active molecules and, for a smaller power of auxiliary emission, allows us to improve the amplitude and relaxation characteristics of the paramagnetic amplifier.

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ON SENSITIVITY OF RADIO RECEIVERS WITH PARAMAGNETIC AMPLIFIERS

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The determination of the gain in sensitivity at reception of regular and noise signals with the use of resonator paramagnetic amplifiers and traveling-wave paramagnetic amplifiers is given.

It is known that the utilization of paramagnetic amplifiers may considerably improve the sensitivity of radio-receiving devices in the centimeter band. Since the internal noises of paramagnetic amplifiers are extremely small, in the use of these amplifiers, the atmospheric and antenna-feeder channel noises play a significant role in the determination of the sensitivity level. Hence, it is practical to find the interrelation which permits one to estimate the possible gain in sensitivity. Here, one must differentiate between devices designed for reception of regular, practically monochromatic signals and devices which receive noise signals. The goal of the investigation performed below is the determination of the gain in sensitivity in both of these cases.

Designating P_0 as the intensity received by an antenna system of a minimally detectible regular signal, without the use of a paramagnetic amplifier, one may write

$$P_0(1 - \alpha_\Phi) = [T_a(1 - \alpha_\Phi) + T_0\alpha_\Phi + NT_0]k\Delta f, \quad (1)$$

where α_Φ is the absorption factor in the antenna-feeder channel; T_a is the effective antenna temperature, conditioned by radio emanations from space and heat radiations from the earth's atmosphere; T_0 is the temperature of the surrounding medium, approximately equal to 300°K, k is Boltzmann's constant; N is the noise factor in the radio receiver; Δf is its bandwidth.

Similarly in the case of the utilization of a paramagnetic amplifier, we find that the intensity P of a barely perceptible signal is determined from the relation

$$P(1 - \alpha)G = [T_a(1 - \alpha)G + \alpha T_0G + T_pG + NT_0]k\Delta f, \quad (2)$$

where G is the power amplification factor of the paramagnetic amplifier; T_p is the effective noise temperature; $\alpha = \alpha_\Phi + \alpha_c - \alpha_\Phi\alpha_c$ is the absorption factor in the antenna-feeder channel when paramagnetic amplifier is used. The difference between α and α_Φ is conditioned by losses in the circulator α_c .

Assuming that the receiving bandwidth in both of the examined cases has the same value, we obtain from (1) and (2) the relation for the gain in sensitivity:

$$\frac{P}{P_0} = \frac{\frac{T_a}{T_0} + (\alpha_\Phi + N) / (1 - \alpha_\Phi)}{\frac{T_a}{T_0} + \left(\alpha + \frac{N}{G} + \frac{T_P}{T_0} \right) / (1 - \alpha)} \quad (3)$$

Under actual conditions the inequalities $N \gg \alpha_\Phi$ and $\alpha \gg T_P/T_0$ most certainly are fulfilled. Then, if amplification is sufficiently large, i.e., if the condition $G \gg N/\alpha$ is satisfied, the resulting expression may be simplified:

$$\frac{P_0}{P} = \frac{T_a + \frac{N}{1 - \alpha_\Phi} T_0}{T_a + \frac{\alpha}{1 - \alpha} T_0} \quad (4)$$

It follows from Equation (4), in part, that when $N = 10$, $T_a = 150^\circ\text{K}$, $\alpha_\Phi = 0.5$ (which corresponds to a feeder with losses of 3 db) and $\alpha = 0.6$ (which corresponds to a circulator with losses of 0.5 db) utilization of a paramagnetic amplifier results in a 10-fold improvement in sensitivity. In a number of cases, it is sufficient to operate at elevations greater than 5° , for which in the centimeter band, T_a takes on the value $T_a < 30^\circ\text{K}$ [1]. If one were to utilize at the same time a channel with low losses ($\alpha_F \simeq 0.1$) with $N = 10$ and $\alpha_C = 0.1$, a 30-fold improvement in sensitivity would result. For elevations of the order of 20° , the magnitude of the gain reaches 40. Corresponding improvements in sensitivity may be obtained in systems which do not use ferrite circulators. This means a transfer from resonator paramagnetic amplifiers to traveling-wave paramagnetic amplifiers for which $\alpha = \alpha_\Phi$, and when $N = 10$, $\alpha_\Phi = \alpha = 0.1$. If $T_a = 30^\circ\text{K}$, the magnitude of the gain in sensitivity is greater than 50, while if the elevation is of the order of 20° , the gain reaches 80. In this way, the use of a paramagnetic amplifier functioning as the input stage of a receiving unit designed for reception of regular signals, sharply increases the sensitivity of the unit. At the same time, the requirements on the bandwidth are conditioned by considerations which have nothing in common with noises.

As is known, the sensitivity of receivers to noise radiation is higher the wider the band of reception. Hence, use of resonator paramagnetic amplifiers, for which a decrease both in the effective input noise temperature and in the reception band may be effected, does not necessarily improve the sensitivity of the radiometer. Consequently, in the investigation of the question of the sensitivity of a radiometer with a resonator paramagnetic amplifier,¹ one must bear in mind the fact that for the given amplifier the relation between the value of the voltage amplification factor $\sqrt{G}$ and the bandwidth Δf_1 is a constant

$$(\sqrt{G} - 1) \Delta f_1 = A. \quad (5)$$

This encourages us to expect an optimum value of the amplification factor for which the sensitivity is especially high.

We shall consider in the further investigation that a radiometer with a resonator paramagnetic amplifier may be described in the following manner.

At the input of the paramagnetic amplifier with a power amplification factor (G) (at the resonance frequency) there are noises with a spectral density, T_1 . Since the frequency characteristic of the resonator paramagnetic amplifier coincides with the resonance curve of a single oscillator, the noise spectrum at the output of the amplifier is in the form

$$S_1(f) = T_1 G F_1(f) = T_1 G \frac{\Delta f_1^2 f^2}{\Delta f_1^2 f^2 + (f_0^2 - f^2)^2}, \quad (6)$$

where f_0 is the resonance frequency. To the noise spectrum $S_1(f)$ are added the input noises of that part of the receiver that follows the resonator paramagnetic amplifier, with a spectral density

¹The inclusion of such an examination seems to us necessary, since the qualitative analysis in the literature [2] contains certain inaccuracies.

$$S_2(f) = T_2. \quad (7)$$

The summation noise spectrum $S_1 + S_2$ is then filtered in the reception channel with a frequency characteristic $F_2(f)$. As a result of this, noises with a spectrum

$$S(f) = F_2(f) [S_1(f) + S_2(f)]. \quad (8)$$

are applied to the square-law detector. At the same time, in accordance with [3] the regular component of the output current is $I = \int_0^\infty S(f) df$, and the spectrum density of the output noises with largest values near zero frequency is $G(0) = 2 \int_0^\infty S^2(f) df$. In our case this results in

$$I = \int_0^\infty (GT_1 F_1(f) + T_2) F_2(f) df, \quad (9)$$

$$G(0) = 2 \int_0^\infty [T_2^2 F_2^2(f) + G^2 T_1^2 F_1^2(f) F_2^2(f) + 2GT_1 T_2 F_1(f) F_2^2(f)] df. \quad (10)$$

For further calculations it is necessary to specify the frequency characteristic $F_2(f)$. We shall assume that the receiver has a rectangular frequency characteristic with a width Δf_2 . In this case the integration is easily performed. According to the determination of the sensitivity [4], the minimum detectable change in the temperature of the input noise is

$$\delta T_1 = a T_1 \sqrt{\frac{\Delta F}{A}}. \quad (11)$$

Here condition (5) is fulfilled under the assumption that $G \gg 1$, and ΔF determines the bandwidth of the output unit.

The coefficient a , determined from

$$a = \frac{1}{\sqrt{2}} \left[\sqrt{G} \frac{c}{1+c^2 + \arctg c} + 4 \frac{T_2}{T_1} \frac{1}{\sqrt{G} \arctg c} + \frac{T_2^2}{T_1^2} \frac{c}{G \sqrt{G} \arctg c} \right]^{1/2}, \quad (12)$$

where $c = \Delta f_2 / 2 \Delta f_1$, reaches a minimum value equal to 1.4 $(T_2/T_1)^{1/4}$ when $G = 4.5 \frac{T_2}{T_1}$ and $\Delta f_2 = 6 \Delta f_1 \approx 3 \sqrt{T_1/T_2} A$. As a result the expression for the best attainable sensitivity of a radiometer with a resonator paramagnetic amplifier is in the form

$$\delta T_1 = 1.4 T_1^{3/4} T_2^{1/4} \sqrt{\frac{\Delta F}{A}}. \quad (13)$$

In the case of a radiometer without a resonator paramagnetic amplifier the gain in sensitivity is given by the relation

$$\frac{\delta T}{\delta T_1} = \frac{0.7 T}{T_1^{3/4} T_2^{1/4}} \sqrt{\frac{A}{\Delta f}}, \quad (14)$$

where Δf_1 is the bandwidth of the receiver of the radiometer without paramagnetic amplifier. Let us note that the optimum for Δf_2 is broad and that in the case that the frequency characteristic of the receiver channel $F_2(f)$ coincides with the resonance curve of a single oscillator, $G_{\text{opt}} = 7 \frac{T_2}{T_1}$, $\Delta f_2 = 8 \Delta f_1 \approx 3 \sqrt{T_1/T_2} A$ and $a_{\text{min}} = 2.3 (T_2/T_1)^{1/4}$.

It is practical to obtain the relation for the dependence of sensitivity on the antenna temperature $\delta T_a / \delta T_0$. For this it is necessary to relate the effective temperature T_1 , T and T_2 with N , the noise factor of the receivers, and the parameters of the high-frequency channel α_Φ and α with the antenna temperature T_a . Here two extreme specific cases may be differentiated.

If a superheterodyne receiver with a traveling-wave, high-frequency amplifier is utilized and if a resonator paramagnetic amplifier is used with a preselector, but in the absence of such an amplifier both mirror channels are utilized, then

$$\frac{\delta T_{a0}}{\delta T_a} = 0,7 \frac{1-\alpha}{1-\alpha_\phi} \frac{N^{1/4}}{\left[\alpha + \frac{T_n}{T_0} + (1-\alpha) \frac{T_a}{T_0} \right]^{1/4}} \sqrt{\frac{A}{\Delta f}}, \quad (15)$$

where the noise coefficient N is determined, as usual, for one of the mirror channels. The same result will be obtained by the employment of a regular amplifier. If the pre-selector is not combined with a resonator paramagnetic amplifier, then the ratio $\delta T_{a0}/\delta T_a$ will decrease by a factor of $\sqrt[4]{2}$.

In the radio-astronomical investigation of a low-temperature source by a good circulator, the relation (15) may be written in the form

$$\frac{\delta T_{a0}}{\delta T_a} = 0,7 \left(\frac{N}{\alpha_\phi} \right)^{1/4} \sqrt{\frac{A}{\Delta f}}. \quad (16)$$

In the absence of a high-frequency amplifier and for a low transconductance of the transformer of the mixer, the relations must be decreased by a factor of $2^{3/4}$. The dependence of the ratio $\delta T_{a0}/\delta T_a$ on the magnitude of N/α_ϕ for the case $\Delta f \simeq A$ is shown by the dotted line in Figure 1. The dashed line in this diagram shows the magnitude of the amplification of the resonator paramagnetic amplifier necessary for the attaining of the corresponding gain.

In this way, in radio-astronomical receivers the utilization of a resonator paramagnetic amplifier is practical, if the value of the transformation of the coefficient of amplification in the bandwidth A is not narrower than the bandwidth of the receiver used in a radiometer not containing a paramagnetic amplifier radiometer. It must also be borne in mind that a resonator paramagnetic amplifier with a gain larger than 20 db apparently operates within sufficient stability.

One must bear in mind the fact that relation (5) is not fulfilled if a traveling-wave paramagnetic amplifier free of regenerative instability is used in the radiometer. The bandwidth of the traveling-wave paramagnetic amplifier is determined by the width of the absorption line of the paramagnetic substance Δf_L , and is attained for a magnitude of amplification G . For the Lorentz form of the absorption line the frequency characteristic of the traveling-wave paramagnetic amplifier has the form

$$F_1(f) = e^{-\frac{(f-f_0)^2}{\Delta f_L^2} \ln G}, \quad (17)$$

where f_0 is the resonance frequency. Assuming, as before, that the receiver connected after the traveling-wave paramagnetic amplifier has a rectangular frequency characteristic of width Δf_2 , one may obtain for a radiometer with traveling-wave paramagnetic amplifier,

$$\delta T_1 = a T_1 \sqrt{\frac{\Delta F}{\Delta f_\pi}}, \quad (18)$$

where

$$a^2 = \frac{\int_0^c e^{-2B \frac{z^2}{1+z^2}} dz}{\left[\int_0^c e^{-B \frac{z^2}{1+z^2}} dz \right]^2} + 2 \frac{T_2}{T_1} \frac{1}{G \int_0^c e^{-B \frac{z^2}{1+z^2}} dz} + \frac{T_2^2}{T_1^2} \frac{c}{G^2 \left[\int_0^c e^{-B \frac{z^2}{1+z^2}} dz \right]^2}. \quad (19)$$

In its turn, $c = \Delta f_2/2 \Delta f_L$ and $B = nG$. The integrals in Equation (19) are not formed

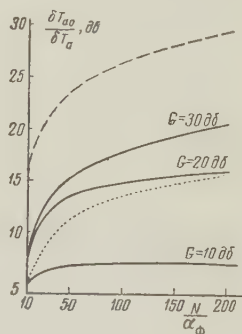


Figure 1

for elementary functions. Results of numerical integration point to an optimum value of the parameter c . This value depends on the amplification: when the gain is 10 db, $C_{\text{opt}} \simeq 1$; when it is 20 db, $C_{\text{opt}} \simeq 0.8$, and when 30 db, $C_{\text{opt}} \simeq 0.6$. Under these optimum conditions it becomes apparent that

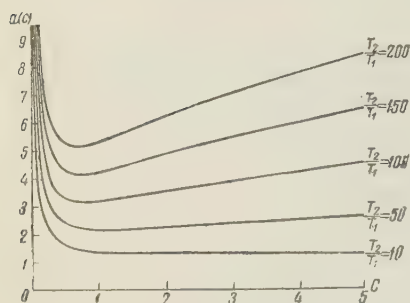


Figure 2

One must note that the optimum for Δf_2 is broad. The dependence of $a(c)$ for a gain of 20 db is given in Figure 2.

Relations (18) - (20) permit us to determine the gain in sensitivity of the radiometer with traveling-wave paramagnetic amplifier under concrete conditions, in a method analogous to that for the resonator paramagnetic amplifier.

Limiting ourselves to the case of radio-astronomical investigation of a low-temperature source, where the magnitude of T_1 is determined by the magnitude of losses in the antenna-feeder channel α_f , while the value of T_2 is determined by the magnitude of the noise factor N , it is easy to obtain the value of the gain in antenna temperature. In Figure 1 the dependence of this gain on the ratio N/α_f are given for gains of 10, 20 and 30 db, under the assumption that Δf_L coincides with the width of the bandwidth Δf of the receiver utilized in the radiometer without a resonator paramagnetic amplifier. It follows from the results obtained that when $\Delta f \simeq \Delta f_L$ a traveling-wave paramagnetic amplifier with a gain of 10 db is practical, since the best results may be obtained with the help of a resonator paramagnetic amplifier. At the same time it is seen that a traveling wave paramagnetic amplifier with a gain of the order of 20 db considerably improves the sensitivity of the radiometer, even in comparison with a resonator paramagnetic amplifier under other conditions. One must, bear in mind the fact that already when $N/\alpha_f > 20$ it is necessary that the gain exceed 20 db to achieve the improvement of a resonator paramagnetic amplifier, and this may lead to instability.

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RADIO TELESCOPE WITH A 22-METER PARABOLIC REFLECTOR (PHYSICAL INSTITUTE OF THE ACADEMY OF SCIENCES OF THE USSR)

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The construction details of a steerable radio telescope with a 22-meter parabolic reflector, which has a needle directivity pattern for 8 mm waves and a 3 db beam width of not worse than two angular minutes, are presented. The method of obtaining an accurate and sufficiently tough reflecting surface which guarantees a high resolution capability is described. The electrical control system of the radio telescope provides the possibility of its rapid shifting to a new position (with a speed of nearly 20° per minute), as well as of comparatively slow motion, necessary when observing astronomical sources of radio radiation.

1. The successful development of radio astronomy is closely bound to progress in the design of radio telescopes of ever increasing dimensions. An increase in the size of reflector-type radio telescopes, which find wide usage in the centimeter and decimeter ranges, presents great difficulties in obtaining a sufficiently accurate and rigid reflective surface. An aperture diameter of the order of $10^3 \lambda$ requires the profile of the surface to be constructed with a relative accuracy of 10^{-4} . Therefore, even in the largest steerable reflector radio telescopes constructed at the present time, it has not been possible to attain symmetrical apertures larger than $10^3 \lambda$, where λ is the smallest wavelength used without a noticeable degradation of the reflector parameters.

It is therefore of interest to describe the attempt of the P.N. Lebedev Physical Institute to construct a large steerable reflector radio telescope, with a symmetrical parabolic reflector, the diameter of which exceeds $10^3 \lambda$. With the diameter $D = 22$ m, the minimum usable wavelength is $\lambda = 0.8$ cm, which, at that wavelength, permits us to obtain a needle pattern, whose 3 db beam width does not exceed 2 angular minutes. The radio telescope was designed at the Physics Institute and a number of design organizations and enterprises during several years. The radio telescope has been in use since 1959. Several radio astronomical observations have been performed with it, among which was the capture at $\lambda = 0.8$ cm of radiations from Venus.

The construction details of the radio telescope, as well as the methods used in its assembly, since they may be of interest in the construction of similar units, are given below.

2. The radio telescope (Figure 1) is in the form of a parabolic reflector with a diameter of 22 m and a focal length of 9.525 m (angular aperture $2\Psi = 120^\circ$), rigidly connected by two large linkage sectors with a 5 m radius and by a horizontal pipe which connects the sectors. The pipe forms the axis about which the reflector is turned in the altitude direction. The pinions of this axis bear against two supporting self-aligning bearings at the upper part of the bearing-turning unit. The latter is in the form of a turntable on balls with a turning diameter of 10 m, to provide the rotation of the reflector along the azimuth. The bearing apparatus for the horizontal axis is placed on the upper platform of the turntable. The rotation mechanisms for the altitude direction are placed on a special platform between the supports to enable the rotation of the reflector from -5° to 95° with respect to the horizontal axis. The mechanisms for rotation in azimuth are placed inside the turntable and enable the rotation of the entire unit within $\pm 180^\circ$. The central control cabin is placed on the upper platform of the turntable. The control cabin contains the central power distribution board, the central control desk, the coordinate transformer, as well as the output and recording blocks of the receiving unit.

A cabin for visual focusing is placed inside of the horizontal pipe. There, an optical telescope-guide (a refractor with a diameter of 110 mm with a wide-angle finder) and a visual focusing desk are located. When visibility is good, the radio telescope may be

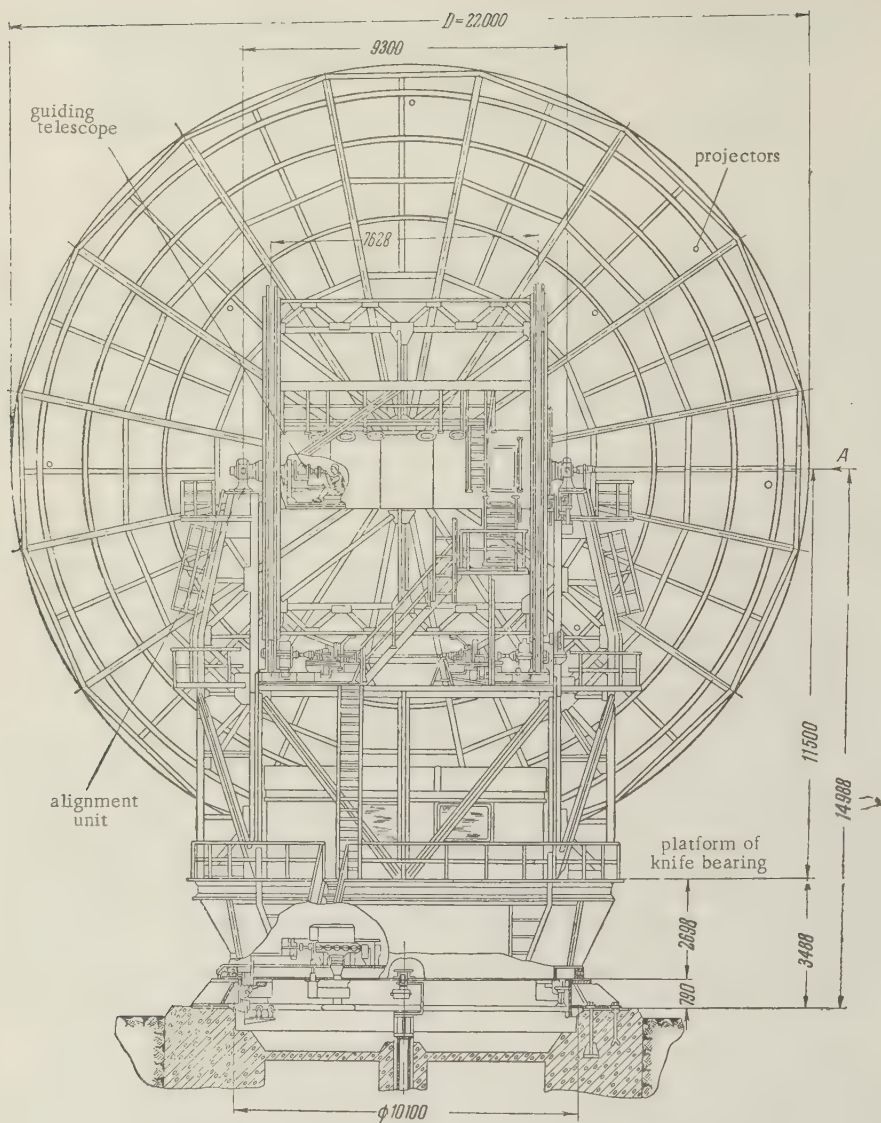


Figure 1a. Main view of radio telescope (rear view).

oriented from this cabin by visual orientation.

In addition to rapid translation, the system of electrical controls provides the possibility of the following slow translations of the radio telescope axis:

a) Automatic tracking of a point on the celestial sphere within the given declination limits of $\pm 30^\circ$, with the aid of an electromechanical coordinate transformer.

b) Semiautomatic observation according to a program determined at certain time intervals by the operator.

c) Placement at an angle determined by the central control cabin.

d) Placement at the determined angles and translation at a velocity given by a command of the operator in the visual focusing cabin.

The locations of the axes are controlled by means of a system of input and output units, and, directly, by the precision azimuth and altitude position limbs. With the latter,

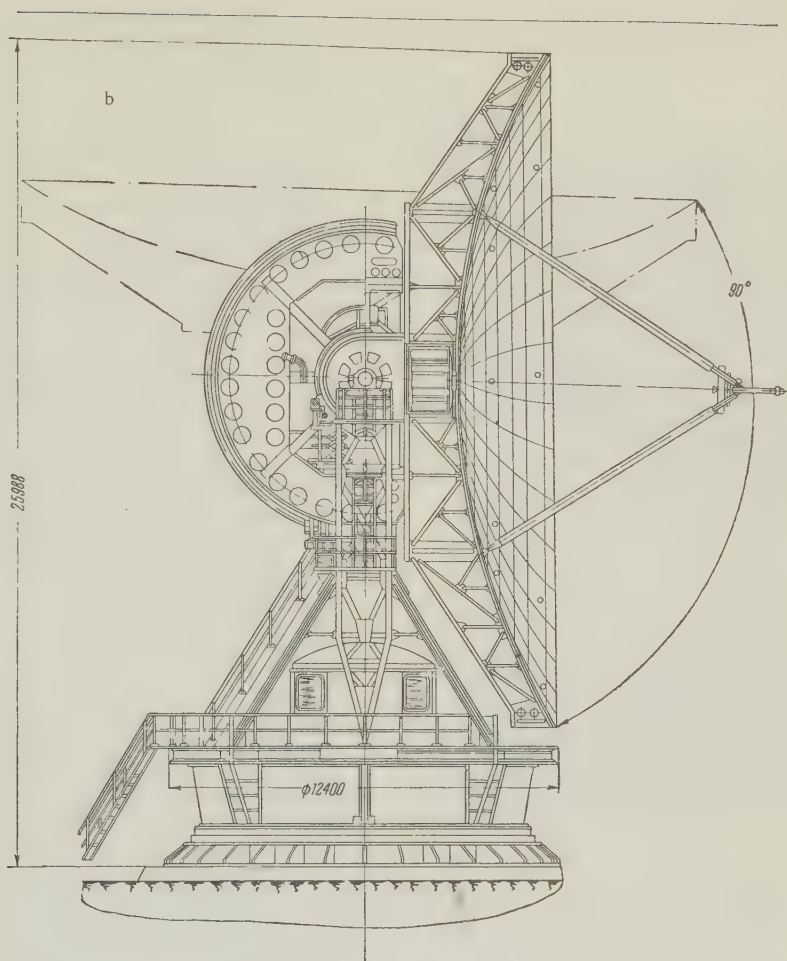


Figure 1b. Main view of radio telescope (side view) - all dimensions in mm.

the position can be calculated with an accuracy of 7.5".

3. In the design and construction of large radio telescopes, especially of those designed for operation at centimeter wavelengths, the building of the reflector poses a difficult problem. The reflector (with a diameter of approximately 15 m) of the radio telescope at the Naval Research Laboratory in Washington, constructed with special accuracy on a lathe, was found to be insufficiently accurate for operation at 0.8 cm.

The difficulties in obtaining an accurate but at the same time durable surface, required a separate solution of each of these two problems. Hence, the described reflector combines a quite durable (rigid) three-dimensional steel frame constructed with relatively rough tolerances (10 - 15 mm) with a coating surface. The latter is attached to the frame by-means of pins which may be adjusted in a direction normal to the working surface and then tightened.

Special care was taken in the construction of sufficiently precise concave knife-edge pattern (template) and of its counterpart, a rotating convex knife-edge pattern. The final shaping of the convex pattern was done at the point of assembly of the reflector. The horizontality of the base line of the concave pattern, with respect to which the parabolic curve was constructed, and the verticality of the axis of rotation of the convex pattern were measured with precision levels in the working position. This procedure eliminated deformation

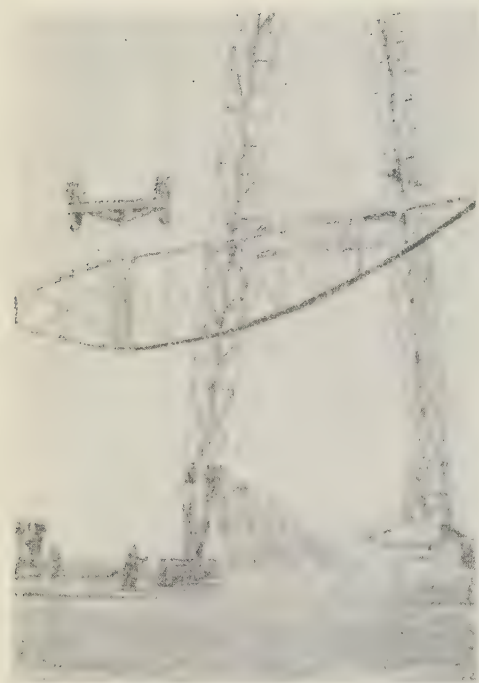


Figure 2. Raising the convex pattern to the assembly platform.

Following the completion of installing the coating, an investigation of deviations of the surface of the reflector from the pattern was performed by measurement of clearances at several hundred points. Statistical analysis of the measurements¹ showed that the radius of correlation ρ of the deviation of the surface from the theoretical form is determined by the technique of attaching the sheets to the frame. In correspondence with the pitch of the rows of supporting pins in the radial and annular directions, the correlation radius turns out to be equal to 200 mm. Deviations at points, separated from each other by more than ρ , are independent of each other. The investigation performed on 200 such points, showed that clearance from the line of the pattern may be represented as sums of a constant clearance, equal to the average value, and as random deviations from the average. These random deviations may be thought of as deviations from a certain parabolic surface, differing from the theoretical one (formed by rotation of the pattern) by the magnitude of the average clearance. The random deviations are distributed according to the normal law, with a dispersion equal to 0.2 mm.

After the completion of assembly and finishing of the reflector coating, the reflector was raised in its assembled form with the aid of a crane and moved to the bearing-rotating unit (Figure 4). The check on the perpendicular placement of the geometrical axis of the reflector and of the horizontal axis of the rotating unit (after a check on the latter with a level) was made by laying the convex pattern over the reflector surface. Another examination of the surface, performed after the final attachment of the reflector with the aid of the pattern, revealed

of the convex pattern under its own weight. The movable sabre-like sections of the convex pattern were exposed and fixed in position following their adjustment with respect to the concave pattern. Then, the convex pattern along with its axis of rotation was moved to the central sleeve of the reflector frame without disassembly (Figure 2). Figure 3 shows the details of attaching and the technique of installing the sheets of the coating on the parabolic surface of the reflector. Nearly 32,000 pins with a pitch of approximately 100 mm were installed and adjusted. The adjustable pins were screwed into openings milled in the elements of the frame. The pins were then adjusted with respect to the convex pattern. Prefabricated aluminum sheets of 6 mm thickness were connected to the pins by means of flat-head screws. The position of the sheets was adjusted in accordance with the pattern. Errors created by the irregularity of the thickness of the sheets and by their local deformations were removed by repeated adjustment of the pins and by copper-smithing (malleting). Taking into account the continuous changes in temperature during the installation of the coating with the aid of control platforms permitted the task to be completed without interruptions. The installation was done in a specially constructed enclosed building with a removable roof.

¹Investigations were performed by O.N. Vladimirova of the Moscow Physicotechnical Inst. The diploma work was under the supervision of A.A. Pistolkors.

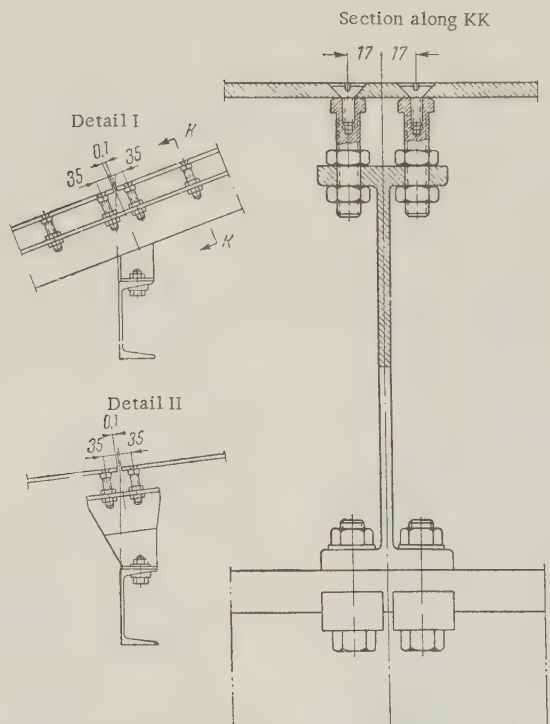


Figure 3. Construction details of attaching the coating to the frame.
Adjustable pins are shown.

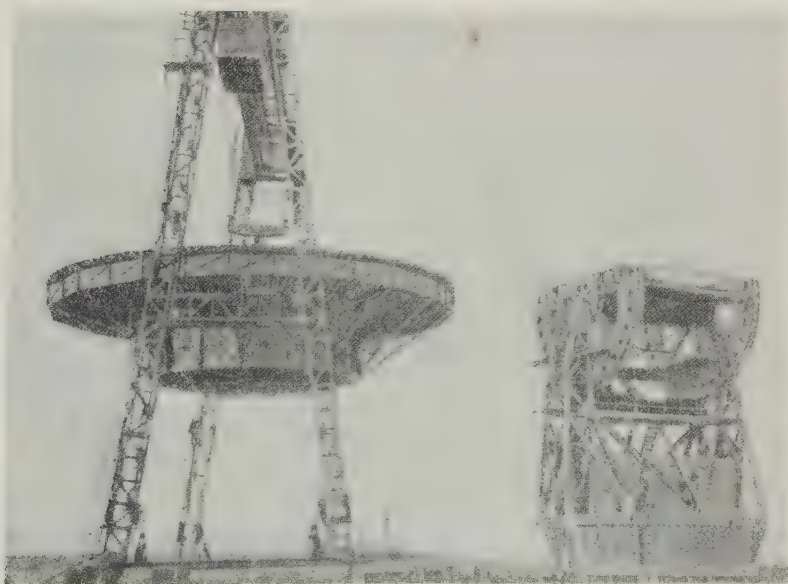


Figure 4. Transfer of the reflector and placement on the bearing-rotating unit.

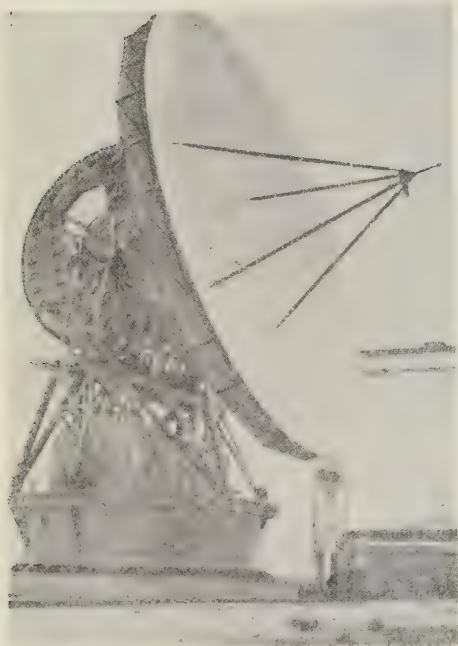


Figure 5. General view of radio telescope after assembly.

4. For the placement of the radiators and receiving units that are always needed near the focus, a four-spindle pyramidal bearing construction was utilized, it being made of thin-walled steel tubes with a diameter of 220 mm, and all being connected at one point below the focus.

The adjustment of the location of the focal point was performed with the aid of a special, precisely measured rotating post (Figure 6), placed along the axis of the reflector at its vertex. The bench-mark platform on the bearing construction was placed on this post precisely at the focal point in such a way that its center coincided with the reflector axis. After removal of the post a special view-finder tube was placed in the direction of the axis, and was bound to the central stopper of the reflector frame. Along this tube, in its turn, the optical axis of the telescope guide was placed. The parallelism of the optical axis was checked by the simultaneity of motion of a star. When the altitude direction of the reflector is changed (from 0 to 90°), the shift of the center of the bench-mark platform with respect to the optical axis of the viewfinder does not exceed 1.5 mm.

The electrical axis was then adjusted by means of cosmic sources of radiation. The verticality and horizontality of the axis of rotation of the reflector were checked by precision levels. The error in the placement of the vertical axis does not exceed ± 0.25 angular minutes; the error in the placement of the horizontal axis is ± 0.18 angular minutes.

Investigations of the influence of the ambient temperature on the surface of the reflector have not yet been performed. The presence of 0.8 mm wide temperature expansion gaps between all sheets of the coating ensures the absence of buckling of the surface with rising temperature. General deformations of the surface, equivalent as a first approximation to a change in the focal distance of the paraboloid, are not excluded.

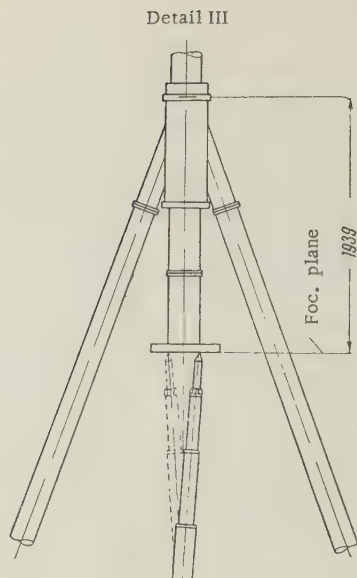


Figure 6. Adjustment of position of focal point using rotating post.

its condition as fully satisfactory; the maximum deviations of the clearance from the average value did not exceed ± 0.3 mm. Taking into account the precision of the pattern (± 0.2 mm), this testified to an accuracy of the surface of ± 0.5 mm from the theoretical profile.

In Figure 5 a general view of the radio telescope is given after its final assembly.

With uniformly changing temperature the focal distance of the paraboloid changes in such a fashion that, for instance, for a change in temperature of $\pm 25^\circ$ the change in focal distance is ± 3 mm. However, the corresponding shift at the ends of the construction, which supports the radiator, fixes the position of the latter with respect to the focus. The difference in the coefficients of linear expansion of steel and aluminum, which leads to a certain additional straightening of the working surface during heating, and to its bending during cooling, leads, as estimates show, to an additional shift in the focus by ~ 0.5 mm.

The oblique measurements of electrical parameters of the reflector have not yet revealed any kind of influence of temperature.

The results of the measurements of these parameters made at wavelengths of 9.6 and 0.8 mm, are included in a separate article [1]. The method of obtaining a precisely parabolic surface used in the construction of the 22-meter reflector may be utilized, with certain improvements if necessary, in the construction of a radio telescope of considerably larger dimensions.

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INVESTIGATIONS OF SOME ELECTRICAL PARAMETERS OF THE ANTENNA OF A 22-METER RADIO TELESCOPE

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Results are given of preliminary investigations of the directivity pattern, coefficient of directivity and of certain other parameters of the parabolic antenna of a 22-meter radio telescope of the P. N. Lebedev Physics Institute, Academy of Sciences USSR. The investigations were performed for waves of 9.6 and 0.8 cm length.

INTRODUCTION

The investigation of antenna characteristics of an accurate 22-meter radio telescope of the FIAN SSSR [1, 2] was filled with considerable difficulties in that, for the 22-m diameter of the reflector the directivity patterns for waves of 3-1 cm are formed at large distances from the radio telescope. Thus, for instance, the Fraunhofer zone for a wave of 3.2 cm begins only at the distance ~ 30 km from the antenna, while for a wave of 0.8 cm - at a distance ~ 120 km. Under these conditions the usual antenna measuring devices are of little use, and it is necessary to use special methods.

Among the latter a specially effective method is one using cosmic sources of radio radiations as output generators [3, 4, 5]. However, new difficulties arise in this case, conditioned by the finiteness of the angular dimensions and the form of the spectral characteristics of the source of cosmic radiations. The small width of the directivity pattern of the radio telescope excludes the use of such extended sources, as the sun and moon for measurements (with the exception of local sources on the sun's disc, concerning which see below), as well as certain extended discrete sources, whose angular dimensions are not known with the necessary accuracy. Besides this, the small magnitude of radiation in the centimeter band, which is characteristic of even the most intense sources, makes measurements of antenna characteristics of a radio telescope at the especially small wavelength that interests us (0.8 cm) extremely difficult.

In connection with this, at the present time only a part of the planned program of measurements, begun at the time of experimental exploitation of the radio telescope, has been performed.

The results of measurements of waves of 9.6 and 0.8 cm are given below. For the 3.2 cm wave, the diagrams obtained by the method described in § 2 were made in two sections, which were found quite similar to theoretical diagrams under the corresponding conditions of excitation. In June, 1960 the antenna parameters were found by us for the 3.2 cm wave, from measurements of the source Tau-A. The width of the pattern at the 3 db level is $6.4' \pm 0.2'$; $A = 185 \text{ m}^2$, $G = 2.25 \cdot 10^6$ (see Astron. Zhurnal, 1961, 38, 1).

1. INVESTIGATION OF PARAMETERS OF THE ANTENNA OF THE RADIO TELESCOPE AT 9.6 cm

The measurement of the parameter of the antenna of the radio telescope at 9.6 cm was performed by use of radiations from intense discrete sources. The most useful sources of 10 cm waves are the sources Cassiopeia - A, Cyg - A, Tau - A and Virg - A; all are very intense and have sufficiently small angular dimensions.

The adjustment of the antenna axis with respect to the view-finder axis preceded the measurement of antenna parameters, as well as the coincidence of the phase center of the exciter, with the focus of the parabolic antenna. The latter was performed by choosing, on the axis of the paraboloid a position of the exciter such that the signal obtained during transit of the source Cassiopeia - A across the unmovable antenna pattern was a maximum. Since the solid angle of the source is much smaller than the effective solid angle of the antenna pattern, the optimum position of the exciter corresponds to the optimum full amplification of the antenna.

Measurements, performed for various positions of the exciter, have shown that the shifting from the optimum position along the axis of the paraboloid by 0.1λ does not decrease the amplification factor of the antenna by more than 2.5%.¹

The adjustment of the electrical axis of the antenna was done by way of comparison of the calculated times of transit of the sources Cassiopeia - A, Cyg - A and Virg - A across the pattern of the unmovable antenna with the times of maxima on the transit curve. The placement of the radio telescope in the calculated position was done with the help of vernier limbs, which coincide to an accuracy better than 10" with the optical axis of the optical guide. The coordinates of the discrete sources were obtained according to published data [4] or else from the NGC catalog (see table)

Source of radiation	α_{1960}	δ_{1960}	α_{1950}	δ_{1950}
Cassiopeia - A	$23^{\text{h}}21^{\text{m}}38^{\text{s}}$	$58^{\circ}35',3$	$23^{\text{h}}21^{\text{m}}42^{\text{s}}$	$58^{\circ}32'$
Cyg - A	$19^{\text{h}}58^{\text{m}}06^{\text{s}}$	$40^{\circ}36',6$	$19^{\text{h}}57^{\text{m}}45^{\text{s}}$	$40^{\circ}35'$
Virg - A	$12^{\text{h}}28^{\text{m}}49^{\text{s}}$	$12^{\circ}36',7$	$12^{\text{h}}28^{\text{m}}48^{\text{s}},6$	$12^{\circ}40'$

¹The necessary relative measurements are performed within an accuracy better than 1%.

The work with the times of transit has shown that the electrical axis coincides with the optical one along the azimuth within an accuracy $\pm 0.25'$.

Along the angle of height (elevation) there was a systematic raising of the electric axis by $2'$ with respect to the optical axis. In further work this difference was taken into account.

Measurement of the directivity pattern of the antenna was also performed by noting the transit of sources Cassiopeia - A and Cyg - A across a stationary antenna. The main planes of the exciter were so oriented that the transit at culmination resulted in a pattern in one of the main sections (E - or H - planes). For this the exciter could be rotated around the axis of the paraboloid by 90° . For a stationary position of the exciter one could also obtain patterns for E- and H-planes, by noting the transit of the source Cassiopeia-A not only at culmination, but also at inflection points in its trajectory (approximately through 2 hours up to or after upper culmination). At intermediate points of the 24-hour trajectory of the sources "oblique-sections" directivity patterns were obtained.

Within the limits of accuracy of the measurements the directivity patterns, as expected, have circular symmetry. For the study of polarization characteristics of cosmic radiation the exciter was constructed in the form of a conic horn with a diameter of 100 mm. Calculations show that an exciter of such dimensions guarantees an approximately even excitation of the reflector in the main sections. In Figure 1 a typical pattern obtained from transits of Cassiopeia-A is shown. The average of the 27 measurements of the width of the pattern at the 3 db level was found to be equal to $19.0' \pm 0.15'$.² The side lobes do not go above 20 db. During the work with transit curves a correction for the finite angular dimension of the sources was taken into account [5]. In the case of a stationary antenna the speed of transit of the sources, as is known, is constant and equal to $v = \cos \delta' / \text{min}$, where δ is the declination of the source. Measurements were performed for a constant time $\tau = 4$ sec. For $v_C = 7.82' / \text{min}$ and $v_S = 11.38' / \text{min}$ (where v_C and v_S are the transit speeds of sources Cassiopeia-A and Cyg-A), the distortions of the shape of the passage curve were sufficiently small.

The determination of the amplification factor of the antenna was performed from the measurement of the intensity of discrete sources of radiation. In radio astronomy, the radiation intensity of celestial objects is usually characterized by the radiation flux density p and by the antenna temperature T_a [6, 7], which are related to each other by the expression

$$p = g \frac{2kT_a}{A}, \quad (1)$$

where A is the effective antenna surface; $k = 1.38 \cdot 10^{-23}$ joules/deg is the Boltzman's constant; g is the coefficient which takes into account the angular dimensions of the source.

In the approximation of the directivity pattern and distribution of radio intensity of the source by Gaussian curves

$$g = 1 + \left(\frac{\varphi_{\text{source}}}{\varphi_A} \right)^2 \quad (2)$$

where φ_{source} is the angular dimension of the source at the 3 db level; φ_A is the width of the directivity pattern of the antenna at the 3 db level.

The antenna temperature of a cosmic source T_a is called, in radio astronomy, the resistance temperature, equal to the output resistance of the antenna, which if connected at the input of the receiver instead of the antenna would give the same noise power in the receiver load as the source.

The method of measuring T_a comes directly from this consideration. It is necessary

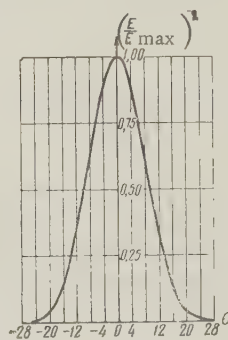


Figure 1. Directivity pattern of the antenna at 9.6 cm.

²The theoretical width at the 3 db level for optimum excitation must be $18'.3$ and $19'.6$ in the H and E-planes, respectively.

to first direct the antenna to a nonradiating portion of the sky, and then on to the measured source, and to note the increase in the indications at the output unit of the receiver. Further, one should substitute for the antenna a resistance equal to its output resistance. It is apparent that the temperature to which this resistance must be heated in order to obtain the same increase in the indication of the output of the receiver will be the antenna temperature of the source.

The method of heating the resistance is complicated and inconvenient and is useful only in a narrow range of temperatures. It is more convenient to use a noise generator, instead of the heated resistance whose power, as is known, also may be expressed in temperature units. We used a gas-discharge noise generator based on type GSh-2 gas-discharge tube.

In order to raise the accuracy of measurements it is necessary that the noise temperature of the generator be commensurable with the measured antenna temperature. In our case this was done by loose coupling with the gas-discharge tube, which is placed, not in the center of the waveguide, as is usual, but maximally shifted toward the narrow wall.

The discrete source Tau-A, intensive enough and having at the same time a relatively small dependence of radiation flux density on frequency was used as a base source. The flux density of the source Tau-A was measured at 9.4 cm [8], where it was found that $p = 8 \cdot 10^{-24}$ watts $\cdot$ m $^{-2}$ $\cdot$ (cps) $^{-1}$. Measurements at 21 cm [9] gave $p = 9.7 \cdot 10^{-24}$ watts $\cdot$ m $^{-2}$ $\cdot$ (cps) $^{-1}$. Extrapolation of the latter result, in accordance with the decrease in the flux density which corresponds to a spectral index 0.28, given in [10], gives for the 9.6 cm wave the magnitude $p = 7.8 \cdot 10^{-24}$ watts $\cdot$ m $^{-2}$ $\cdot$ (cps) $^{-1}$.

Taking the average of the given values $p = 7.9 \cdot 10^{-24}$ watts $\cdot$ m $^{-2}$ $\cdot$ (cps) $^{-1}$ and using the antenna temperature of source Tau-A, $T_a = 52.3^\circ \pm 0.5^\circ$, from our measurements, we obtain the effective antenna surface $A = 190 \text{ m}^2 \pm 15\%$.

The error in the determination of the magnitude A is conditioned basically by possible inaccuracies in the initial data we used concerning the flux of Tau-A.

The angular dimension of source Tau-A necessary for the determination of the coefficient was taken equal to $4'$ [11].

The amplification factor for the antenna was determined using the known relation

$$G_{\text{real}} = \frac{4\pi A}{\lambda^2} = 2.6 \cdot 10^5 \pm 15\%. \quad (3)$$

The semiempirical calculation of the amplification factor, performed by integration of the measured directivity pattern within the limits of the main lobe, gave

$$G_0 = 3.8 \cdot 10^5.$$

Introducing, with the aid of relation

$$G_{\text{real}} = (1 - \beta) G_0 \quad (4)$$

the magnitude β - the coefficient of dispersion characterizing the influence of side and reverse lobes of the pattern on the decrease in the amplification of the antenna - we obtain (from given measurements) $\beta = 0.32$.

The effective surface factor is equal to 0.59. Here, one takes into account the fact that nearly 15% of the aperture surface is shaded over by a four-pivoted girder, bearing the exciter in such a fashion that $S_{\text{geom}} = 0.85 \pi \frac{D^2}{4}$ where D is the diameter of the aperture.

2. INVESTIGATION OF ANTENNA PARAMETERS AT 0.8 cm

Because of the reasons indicated above, investigation of antenna parameters at 0.8 cm using stellar sources of radiations have not yet been performed, with the exception of an estimate of the width of the directivity pattern which we discuss below.

The directivity pattern of the antenna of the radio telescope at 0.8 cm was investigated by a different method [12], in which the transmitter is located on the earth and the measurement is performed in the Fresnel (and not the Fraunhofer) zone.³ The method consists in the creation of an additional dephasing at the aperture of the paraboloid, which compensates

³ As shown above, when $\lambda = 0.8$ cm and $D = 22$ m the Fraunhofer zone begins at $L = 120$ km.

for dephasing caused by the finite distance to the transmitter. The compensation may be guaranteed by the displacement of the exciter of the paraboloid a certain distance b from focus.

If the displacement of the exciter from the focus is $b \ll f$, where f is the focal distance, the noncophasing at the opening due to the displacement of the exciter from the focus may be represented in the form

$$\psi(x) \simeq kb \frac{1 - \frac{x^2}{4f^2}}{1 + \frac{x^2}{4f^2}}, \quad (5)$$

where x is the distance of the point on the opening from the axis of the paraboloid.

The dephasing due to the finite distance to the transmitter is

$$\varphi(x) \simeq \frac{kx^2}{2R}, \quad (6)$$

where R is the distance to the transmitter.

The condition for compensation is $\psi(x) + \varphi(x) = kb$. Depending on the parameter h/f , where $h = D^2/16f$ is the depth of the paraboloid, and depending on the conditions of its excitation, the function $\psi(x)$ may be approximated by one of the following functions:

$$\psi_1(x) \simeq -\frac{kbx^2}{2f^2}; \quad \psi_2(x) \simeq -\frac{kbx^2}{2f^2} \frac{1}{1 + \frac{D^2}{16f^2}}, \quad (7)$$

where the constant which contains the phase shift kb is neglected. For relatively deep paraboloids, a class that includes the one used in the investigations ($D = 22$ m, $f = 9.525$ m), with $h/f > 0.2$, the second approximation fits better (ψ_2). For the conditions of actual measurements a convenient position of placement of the transmitter was found to be the trigonometric point which is extended from the radio telescope almost precisely to the south by $R = 3250$ m.⁴

From the condition $\psi_2(x) + \varphi(x) = 0$ we find for this case $b = 37$ mm; here $b/f = 0.004$. As transmitter during the measurements, a klystron generator with an attenuator and a small horn antenna, placed at a height of 6 m above ground level was utilized. The directivity patterns were obtained by the slow passage of the radio telescope antenna along the azimuth or along the elevation with measurement of the location of the axis along the limb. Thus, the optimum position of the axis was found on a different coordinate. In order to decrease errors, brought about by the detuning of the transmitter and heterodyne receiver, repeated passages were performed with controlled frequency. For the displacement of the exciter from the focus, the high-frequency unit was mechanically moved along the axis of the paraboloid. The patterns were taken for the calculated position of the exciter ($b = 37$ mm) as well as for deviations from the calculated value by 5, 10 and 15 mm. A comparison among themselves of the patterns obtained in this fashion showed, with an accuracy of ± 5 mm [2], coincidence of the theoretical focus with the best (in the sense of sharpness of directivity pattern and level of side lobes) position found for an exciter in the form of an open end of a circular waveguide of diameter of 6 mm.

In Figure 2 a typical directivity pattern in the H-plane (obtained for vertical polarization of the E sector by passage along the azimuth) is shown. The width of the pattern in the H-plane at the 3 db level, obtained by averaging several recorded values for optimum position of the exciter, was $1.7' \pm 0.1'$. The pattern in the E-plane was obtained (in consequence of difficulties in rotating the exciter) by passage along angular direction. In this measurement the influence of the earth was strongly felt. The width of the pattern at the 3 db level was found to be equal to $2.1' \pm 0.1'$.

For optimum excitation the width of the pattern must be $1.6'$, in the H-plane and $1.7'$ in the E-plane. The level of the first side lobe was equal to -12.2 db. Subsequent lobes were clearly visible at a raised sensitivity of the receiver and faded monotonically.

Estimates of the width of the directivity pattern of the antenna at 0.8 cm were also performed by recording radiations from local sources on the sun's disc. The smallest

⁴This distance was determined by angular measurements.

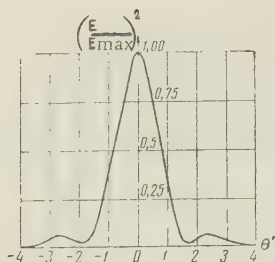


Fig. 2. Directivity pattern of antenna in H-plane at 0.8 cm.

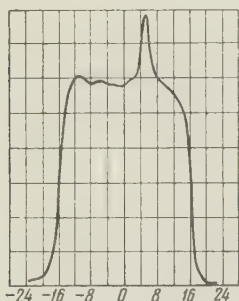


Fig. 3. Record of passage of the directivity pattern of an H-plane, 0.8 cm antenna across the sun's disc.

width recorded at a level of 3 db. from the maximum, uncorrected for the final width of the radiating regions, was $2.2' - 2.3'$. Considering that the minimum dimension of the radiating regions $\geq 1'$ and taking the normal distribution of intensity [5] we obtain the width of the pattern as $\sim 2.0'$. The directivity pattern of the antenna was also estimated from the character of the slope of the recording of solar radiations. Taking into account the distribution of radio intensity along the sun's diameter and differentiating the curve of growth or decay of signal, we obtained as the average value of the width of the pattern at the 3 db level in the H-plane $1.7' - 1.8'$.

In Fig. 3 is shown a typical recording of the passage of the directivity pattern of the radio telescope antenna for 0.8 cm waves across the solar disc in the region of heightened radiation. It follows that the above-described estimates of the width of the pattern, obtained from recordings of solar radiation have an illustrative character, proving at the same time the correctness of the data obtained by direct measurements with a transmitter.

The determination of the amplification factor of the antenna for $\lambda = 0.8$ cm can not yet be performed by direct measurement. We limit ourselves, therefore, to a semiempirical calculation of the amplification factor on the basis of the measured directivity pattern.

As is known,

$$G = \frac{4\pi}{\int_{4\pi} F(\theta, \varphi) d\Omega}, \quad (8)$$

where F is the power directivity pattern. A graphical calculation of the integral in (8) was performed for the main and first side-lobes. As a result of the calculation we obtained

$$G = 3.4 \cdot 10^7 \pm 10\%.$$

At the same time, taking the integral only over the main lobe, we obtain

$$G_0 = 4.2 \cdot 10^7 \pm 10\%.$$

Relating G and G_0 by an expression similar to (4), we obtain $G = (1 - \beta') G_0$,

from which $\beta' = 0.20$.

In this way one may estimate only a portion of the dispersion. Since we cannot determine G_{real} we may approximate it on the basis of the following reasoning. Assuming the dispersion at $\lambda = 0.8$ cm to be near the measured value at $\lambda = 9.6$ cm and equal to $\beta = 0.35$, we obtain

$$G_{\text{real}} = 0.65 G_0 = 2.75 \cdot 10^7 \pm 20\%.$$

The corresponding value $A = 150 \text{ m}^2 \pm 20\%$, and the coefficient of utilization factor of the unshaded surface is equal to 0.45. Substituting the full coefficient of dispersion $\beta = 0.35$ for the coefficient β' , one may come to the conclusion that in the farther side and reverse lobes approximately 15% of the energy is dissipated.

As already stated, the given results have a preliminary character. Subsequent measurements will permit us to obtain more detailed knowledge of the characteristics of the radio telescope antenna, including the level and shape of the side lobes and polarization properties, as well as the influence of statistical characteristics of the surface of the reflector

on its parameters in the 0.8 cm range.

At the same time one may, from the performed investigations draw the conclusion that the accuracy maintained in the construction of the reflector surface guaranteed the obtaining of directivity patterns at 0.8 cm, close to theoretical, and that in the case of optimum excitation the value of the utilization factor of the aperture was close to normal.

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INFLUENCE OF SIGNAL-GENERATOR FREQUENCY FLUCTUATIONS ON THE SENSITIVITY OF RADIO SPECTROSCOPES WITH TRANSIT AND REFLECTOR CAVITIES

A.K. Piskunov and V.I. Muromtsev

An estimate of the magnitude of dispersion of frequency noises in radio spectroscopes with transit and reflector cavities is presented. The obtained results can be utilized for slow and small fluctuations of the frequency of the signal generator.

INTRODUCTION

The quality factor of a cavity, its matching with the waveguide channel and the stability of the generator frequency determine the magnitude of the signal/noise ratio at the input of the radio spectroscopy receiver.

In the present article a comparison is performed of the signal/noise ratio at the receiver input for circuits with transit and reflector cavities. By "signal" is understood the change in the amplitude of a transit or reflected wave caused by the paramagnetic absorption. The main questions on the matching of cavities with a UHF channel are examined

in [1]. A detailed analysis of conditions for matching in the case of reflector circuits is given in [2].

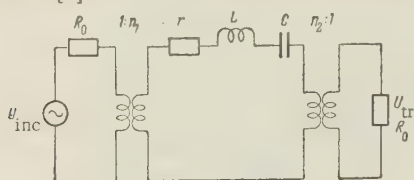


Fig. 1. Equivalent circuit of a waveguide channel with transit cavity: R_0 —wave resistance of the channel; r —equivalent resistance of losses in cavity with model; L and C —equivalent inductance and capacitance of cavity with model.

Let us examine in more detail the circuit with a transit cavity. The determination of conditions for matching in the circuit with a transit cavity is based on the assumption that the coupling between the cavity and waveguide channel is described by the equivalent circuit, presented in Fig. 1.

The transfer circuit is conveniently described by the transmission coefficient K , which is determined as the ratio of voltage on the matched load U_{tr} to the generator voltage U_{inc} :

$$K = \frac{U_{tr}}{U_{inc}}. \quad (1)$$

The transmission factor for the circuit of Fig. 1 is determined from

$$K = \frac{n_1 n_2 R_0}{n_1^2 R_0 + n_2^2 R_0 + Z_r}, \quad (2)$$

where

$$Z_r = r + i \left(\omega L - \frac{1}{\omega C} \right) = r (1 + iy) \approx r \left(1 + i \frac{\Delta \omega}{\Delta \omega_0} \right);$$

$\Delta \omega = \omega - \omega_0$ is the detuning of the generator frequency from the cavity frequency; $\Delta \omega_0$ is the half-width of the resonance curve at the 0.7 level.

The transmission factor at resonance frequency is

$$K_r = \frac{n_1 n_2 R_0}{n_1^2 R_0 + n_2^2 R_0 + r}. \quad (3)$$

Let the paramagnetic absorption lead to an increase in r by the magnitude Δr . This leads to a corresponding change in the amplitude of the transit wave U_{tr} by the value ΔU_{tr} . Assuming that Δr is small, we will obtain

$$\Delta U_{tr} = \frac{\partial K_r}{\partial r} U_{tr} \Delta r = - \frac{n_1 n_2 R_0}{(R_0 n_1^2 + R_0 n_2^2 + r)^2} U_{tr} \Delta r. \quad (4)$$

Analysis of relation (4) shows that when

$$\frac{R_0 n_1^2}{r} = \frac{R_0 n_2^2}{r} = \frac{1}{2} \quad (5)$$

the magnitude of the change in the amplitude of the transit wave ΔU_{tr} will be maximum and will be determined from

$$\Delta U_{tr \max} = - \frac{1}{8} U_{inc} \frac{\Delta r}{r}. \quad (6)$$

Equation (5) determines the condition of optimum matching in the spectroscopy with transit cavity, for which the change in the amplitude of the transit wave, conditioned by paramagnetic absorption will be maximum. The transmission factor for optimum matching is equal to 1/4. The dependence of relative change in signal on the transmission factor K_r for $n_1 = n_2$ is shown on Fig. 2. The dependence of the modulus of the transmission factor on relative detuning $y = \Delta \omega / \Delta \omega_0$ is conveniently represented in the form

$$|K| = \frac{\sqrt{\beta_1 \beta_2}}{\sqrt{(1 + \beta_1 + \beta_2)^2 + y^2}},$$

where

$$\beta_1 = \frac{R_0 n_1^2}{r}; \quad \beta_2 = \frac{R_0 n_2^2}{r}. \quad (7)$$

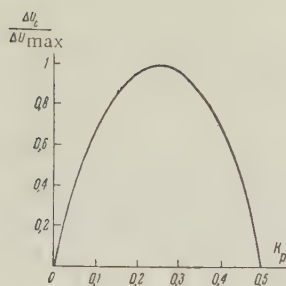


Figure 2. Dependence of the relative change in signal on the transmission factor K_R when $n_1 = n_2$.

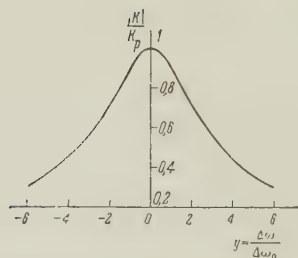


Figure 3. Dependence of the relative change in signal* on the magnitude of detuning for optimum matching of cavity with the UHF channel.

The coefficients β_1 and β_2 are usually called coupling coefficients.

In Figure 3 a graph of the dependence of the relative change in the transfer constant on the magnitude of detuning for the case of optimum matching is shown.

In the circuit with reflector cavity in the case of optimum matching ($\Gamma_r = 0$) the voltage amplitude at the receiver input is equal to zero. In the circuit with transit cavity ($\beta_1 = \beta_2 = 1/2$; $K_R = 1/4$) the voltage at the receiver input is equal to a 1/4 of the amplitude of the incident wave U_{inc} .

For optimum conditions of matching, the signals in the reflector and transit circuits are determined from

$$\Delta U_{refl \max} = \frac{1}{2} \frac{\Delta r}{r} U_{inc}, \quad (8)$$

$$\Delta U_{tr \max} = -\frac{1}{8} \frac{\Delta r}{r} U_{inc}.$$

From Equations (8) it follows that the magnitude of signal in the reflector circuit is four times larger than the signal in the transit circuit. The matching in the reflector and transit circuits is not critical. The change in the modulus of the coefficient of reflection Γ_r in the limits from 0 to 0.1 leads to a decrease in the signal by no more than 1%.

In the transit circuit the change in the transfer constant from 1/5 to 1/3 leads to a decrease in the signal by not more than 5%. The magnitude of the magnetic component of the high-frequency field in the reflector and transit cavities for optimum conditions of matching is determined from the relations

$$H_{refl} = c_1 I_{refl} = c_1 \frac{U_{inc}}{2 \sqrt{R_0 r}}, \quad (9)$$

$$H_{tr} = c_1 I_{tr} = c_1 \frac{U_{inc}}{2 \sqrt{2} \sqrt{R_0 r}},$$

where C_1 is a coefficient of proportionality; I_{refl} , I_{tr} are the currents in the reflector and transit cavities.

It follows from Equations (9) that for optimum conditions of matching and for the same amplitude of the incident wave the magnitude of the high-frequency magnetic field in the

*Translator's Note: Apparently a mistake. Should be "transfer coefficient".

transit cavity is smaller than that in the reflector cavity by a factor of $\sqrt{2}$ and consequently, the intensity of paramagnetic absorption in the transit cavity is half of that in the reflector cavity.

1. INFLUENCE OF INSTABILITY OF FREQUENCY ON SENSITIVITY OF SPECTROSCOPE WITH TRANSIT CAVITY

The amplitude and frequency of actual generators are not strictly constant, but can be represented as random functions. In radio spectroscopy fluctuations of amplitude and frequency decrease the sensitivities of spectrometers. An especially profound influence on sensitivity is frequency instability. Let us examine the influence of frequency instability, under the assumption that the amplitude of the generator voltage is constant.

The generator frequency can be represented in the form

$$\omega = \omega_{av} + \Delta\omega_H(t), \quad (10) \quad (10)$$

where ω_{av} is the average value of frequency; $\Delta\omega_H(t)$ is the deviation of frequency from the average value.

Instability of the generator frequency has fundamental as well as technical origin [3].

Practically the technical reasons for frequency instability are: 1) instability of feeder sources; 2) effect of flicker; 3) microphonic effect.

Stability of feeder sources plays an important role. It is known, for instance, that a 1mv change in voltage at the reflector electrode of a klystron may lead to a 1.5-2 kc change in the frequency of the klystron generator. Instability of the generator frequency has a large number of independent, random causes; hence, one may assume that the frequency deviation from the average value obeys the normal law.

Let us examine the influence of frequency instability in the transit circuit. Let us limit ourselves to the case when the average frequency of the generator is equal to or is near to the cavity frequency and that the dispersion of frequency fluctuations does not exceed 50 kc, which is practically realized in spectrometers with signal-generator feeder sources of sufficiently high quality. Let us also assume that the spectrum of frequency instability lies within the limits 0 to 20 kc. The assumption allows us, in the calculation of frequency noises, to make use of the instantaneous-frequency method [4]. The obtained results can be utilized in spectrometers with modulation of the magnetic field in the region of sound frequencies.

In accordance with (1) and (7) the amplitude of a transit wave for small detunings, may be written as

$$U_{tr} \simeq \frac{\sqrt{\beta_1\beta_2}}{1 + \beta_1 + \beta_2} \left(1 - \frac{1}{2(1 + \beta_1 + \beta_2)^2} y^2 \right) U_{inc}. \quad (11) \quad (11)$$

A change in the frequency of the incident wave will lead to a change in y , i.e., to a change in the transfer constant. Consequently, instability of the frequency of the incident wave leads to a corresponding instability of the amplitude of the transit wave, which is also called frequency noise.

The dispersion and spectrum of amplitude fluctuations of the transit wave depend on detuning of both the average frequency of the generator and the cavity frequency and on the dispersion and spectrum of instability of the generator frequency.

Let us introduce the designation: $\Delta\omega_1 = \omega_0 - \omega_{av}$ equal to the detuning between the cavity frequency and the average generator frequency; $\sigma_f^2 = \Delta\omega^2(t)$, the dispersion of frequency instability; $R_f(r)$ the coefficient of correlation of frequency deviation $\Delta\omega_H(t)$; $F_f(\Omega)$ the spectrum density of frequency deviation; $\sigma_{tr}^2 = (U_{tr} - \bar{U}_{tr})^2$ the dispersion of amplitude instability; $R_{tr}(r)$, the coefficient of correlation of amplitude instability and let $F_{tr}(\Omega)$ be the spectrum of amplitude instability.

It is convenient to represent the amplitude of the transit wave in the form

$$U_{tr} = \frac{\sqrt{\beta_1\beta_2}}{1 + \beta_1\beta_2} \left[1 - \frac{1}{2(1 + \beta_1 + \beta_2)^2} \left(\frac{\Delta\omega_1 + \Delta\omega_H}{\Delta\omega_0} \right)^2 \right] U_{inc} \quad (12) \quad (12)$$

or

$$U_{tr} = \alpha_0 + \gamma\Delta\omega_H + \beta\Delta\omega_H^2, \quad (13) \quad (13)$$

where

$$\alpha_0 = \frac{\sqrt{\beta_1 \beta_2}}{1 + \beta_1 + \beta_2} \left[1 - \frac{1}{2(1 + \beta_1 + \beta_2)^2} \left(\frac{\Delta \omega_1}{\Delta \omega_0} \right)^2 \right] U_{\text{inc}};$$

$$\gamma = \frac{1}{1 + \beta_1 + \beta_2} \frac{\Delta \omega_1}{\Delta \omega_0} U_{\text{inc}};$$

$$\beta = \frac{\sqrt{\beta_1 \beta_2}}{2(1 + \beta_1 + \beta_2)^2 \Delta \omega_0^2} U_{\text{inc}}.$$

The correlation function of fluctuations of the transit wave, corresponding to (13) is determined from relation [5]

$$B(\tau) = \sigma_{\text{tr}}^2 R_{\text{tr}}(\tau) = \gamma^2 \sigma_f^2 R_f(\tau) + 2\beta^2 \sigma_f^4 R_f(\tau). \quad (14)$$

The dispersion of amplitude of the transit wave is equal to

$$\sigma_{\text{tr}}^2 = \gamma^2 \sigma_f^2 + 2\beta^2 \sigma_f^4. \quad (15)$$

The spectrum density of fluctuations of amplitude will be determined by a straight Fourier transformation of the correlation function

$$F_{\text{tr}}(\Omega) = 4 \int_0^{\infty} B(\tau) \cos \Omega \tau d\tau.$$

Let us examine in greater detail the dependence of the root-mean-square deviation of the transit wave amplitude σ_{tr} on detuning and the root-mean-square frequency σ_f .

For greater clarity let us limit ourselves to the case of optimum matching. Substituting into (15) the values γ^2 and β^2 and taking into account the fact that $\beta_1 = \beta_2 = 1/2$, we will obtain after elementary transformations

$$\sigma_{\text{tr}} = \frac{\sqrt{2}}{32} \frac{\sigma_f}{\Delta \omega_0} \left[\sqrt{\left(\frac{\sigma_f}{\Delta \omega_0} \right)^2 + 2 \left(\frac{\Delta \omega_1}{\Delta \omega_0} \right)^2} \right] U_{\text{inc}}. \quad (16)$$

In the special case of precise tuning ($\Delta \omega_1 = 0$)

$$\sigma_{\text{tr}} = \frac{\sqrt{2}}{32} \left(\frac{\sigma_f}{\Delta \omega_0} \right)^2 U_{\text{inc}}.$$

For detuning, when $\Delta \omega_1 > 3 \sigma_f$, one may approximately consider that

$$\sigma_{\text{tr}} \simeq \frac{1}{16} \frac{\Delta \omega_1}{\Delta \omega_0} \frac{\sigma_f}{\Delta \omega_0} U_{\text{inc}}.$$

The given relations show that the root-mean-square deviation of fluctuations of the transit wave amplitude is proportional to the incident wave amplitude U_{inc} .

For the case of precise tuning the root-mean-square deviation σ_{tr} is proportional to the square of the ratio of the root-mean-square frequency deviation to the half-width of the cavity resonance curve.

For the case of detuning ($\Delta \omega_1 > 3 \sigma_f$), the root-mean-square deviation of the transit wave amplitude is proportional to the ratio of the root-mean-square frequency deviation to the half-width of the resonance curve.

Let us take a numerical example.

Let $U_{\text{inc}} = 4.5$ v (for a standard rectangular waveguide of dimensions 10×23 mm this corresponds to a power of 10 mw); $\sigma_f = 20$ kc [which from (6) and (7) corresponds to good-quality klystron generators]; $\Delta \omega_0 = 1$ Mc (for a 3.2 cm wave this corresponds to a quality factor for the cavity equal to 5000).

For this case, if tuning is precise, the root-mean-square amplitude of the transit wave is equal to $\sim 7.5 \cdot 10^{-5}$ v. For detuning by 100 kc ($\Delta \omega_1 = 0.1 \omega_0$)

$$\sigma_{\text{tr}} \simeq 5 \beta_1 \cdot 10^{-5} \text{ v}.$$

2. INFLUENCE OF FREQUENCY INSTABILITY ON SENSITIVITY OF SPECTROSCOPE WITH REFLECTOR CAVITY

In the analysis of the influence of frequency instability in the reflector circuit, as before, we shall assume that the average frequency of the generator is equal to or is near to the cavity frequency and that the spectrum of frequency instability lies in the region of sound frequencies.

The dependence of the transit wave amplitude on detuning when $y \leq 0.3$ is determined from the approximate relation [12]

$$U_{\text{refl}} \simeq \frac{1 + \Gamma_r}{2} \sqrt{\left(\frac{2\Gamma_r}{1 + \Gamma_r} \right)^2 + y^2} U_{\text{inc}}.$$

In the special case of optimum matching ($\Gamma_r = 0$)

$$U_{\text{refl}} \simeq \frac{1}{2} |y| U_{\text{inc}}.$$

For the case of precise tuning ($\Delta\omega_1 = 0$) the root-mean-square deviation of fluctuation of the reflected wave amplitude is

$$\sigma_{\text{refl}} = \frac{1}{2} \sqrt{1 - \frac{2}{\pi} \frac{\sigma_f}{\Delta\omega_0}} U_{\text{inc}}. \quad (17)$$

For detuning, when $\Delta\omega_1 \gg 3\sigma_f$, one may approximately consider that

$$\sigma_{\text{refl}} \simeq \frac{1}{2} \frac{\sigma_f}{\Delta\omega_0} U_{\text{inc}}.$$

Let us examine a numerical example.

Let $U_{\text{inc}} \simeq 4.5$ v, $\sigma_f = 20$ kc, $\Delta\omega_0 = 1$ Mc. In this case, for precise tuning, the root-mean-square deviation of fluctuation of the reflected wave amplitude is

$$\sigma_{\text{refl}} \simeq 27 \cdot 10^{-3} \text{ v}.$$

With an increase in $|\Gamma_r|$ noises caused by frequency instability decrease. When $\frac{2|\Gamma_r|}{1 + \Gamma_r} \geq \frac{1}{3} |y|$ the reflected wave amplitude may be represented as

$$U_{\text{refl}} \simeq \Gamma_r \left[1 + \frac{1}{8} \frac{(1 + \Gamma_r)^2}{\Gamma_r^2} y^2 \right] U_{\text{inc}}.$$

For this case, the root-mean-square deviation of fluctuation of the reflected wave amplitude will be determined by the relation

$$\sigma_{\text{refl}} = \frac{\sqrt{2}}{8} \frac{(1 + \Gamma_r)^2}{|\Gamma_r|} \frac{\sigma_f}{\Delta\omega_0} \sqrt{\left(\frac{\sigma_f}{\Delta\omega_0} \right)^2 + 2 \left(\frac{\Delta\omega_1}{\Delta\omega_0} \right)^2} U_{\text{inc}}, \quad (18)$$

when $\Gamma_r = 0.1$ and for precise tuning, the root-mean-square deviation of fluctuation of reflected wave amplitude will be equal to

$$\sigma_{\text{refl}} \simeq 4 \cdot 10^{-3} \text{ v}.$$

From relations (15) and (18) it is easy to obtain

$$\frac{\sigma_{\text{refl}}}{\sigma_{\text{tr}}} = \frac{1}{4} \frac{(1 + \Gamma_r)^2}{\Gamma_r} \frac{(1 + \beta_1 + \beta_2)^2}{\sqrt{\beta_1 \beta_2}}. \quad (19)$$

In part, when $\beta_1 = \beta_2 = 1/2$ and $\Gamma_r = 0.1$ the ratio $\sigma_{\text{refl}}/\sigma_{\text{tr}} \simeq 50$. With an increase in $|\Gamma_r|$ the magnitude of frequency noises in the reflector circuit is decreased. When $\Gamma_r = 1/4$ the ratio $\sigma_{\text{refl}}/\sigma_{\text{tr}} = 25$. For the case of coupling larger than critical ($\Gamma_r = -1/4$) the ratio $\sigma_{\text{refl}}/\sigma_{\text{tr}} = 9$.

CONCLUSION

Depending on the power level of the generator and on the receiver circuit, the sensitivity of the radio spectroscope may be limited either by noises in the receiver or by noises caused by frequency instability of the signal generator.

In order to increase the sensitivity of radio spectroscopy it is necessary, first of all, to increase the receiver sensitivity, and, secondly to decrease the magnitude of frequency noises.

Two ways of decreasing frequency noises are possible.

1. Increasing the stability of the signal generator frequency (decreasing the dispersion of frequency instability).

2. The corresponding choice, tuning and matching of the elements of the waveguide channel.

In this work a qualitative estimate of frequency noises in transit and reflector circuits was presented for the important case in practice when the average frequency of the generator is near or equal to the cavity frequency. The presented relations and numerical examples show that fluctuations of the generator frequency have an especially great significance in the reflector circuit, especially for matching, when $|\Gamma_r| < 0.1$. Frequency noises in the transit circuit are approximately smaller by two orders of magnitude than frequency noises in the reflector circuit.

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BRIEF COMMUNICATIONS

H_{02} WAVE FILTER IN A CIRCULAR WAVEGUIDE

M. V. Persikov

Investigations performed in the last years have shown that waveguide lines with low losses may be created for the H_{01} wave in a circular waveguide [1]. However, the H_{01} wave in a circular waveguide is transformed at nonuniformities of the lines (junctions of two portions of a waveguide, matching transitions, bends, and so on) into waves of other form, thus increasing losses. When the proper choice of the construction of nonuniform portions of the line is made, the transformation of H_{01} waves into waves of other (parasitic) forms may be made quite small in magnitude. But even in this case, the appearance of parasitic-type waves leads to distortion of the signal due to formation in the lines of a current flow [2], while any resonance phenomena in the parasitic wave leads to a considerable increase in losses [3]. Hence, it is necessary to connect into the line filters which damp parasitic waves.

The unsymmetrical waves H_{mn} ($m \geq 1$) and E_{mn} waves have longitudinal currents in the waveguide walls and may be filtered by filters with ringlike wall structure [4]. H_{0n} waves have only transverse currents in the waveguide walls and go through the ring-mode filter practically without losses.

In connection with this, during the transmission of a signal by the H_{01} wave great difficulties arise in connection with the necessity of filtering out H_{0n} ($n \geq 2$) waves, formed at nonuniformities of the waveguide line. Most troublesome is the H_{02} wave, since it arises, as a rule, with a specially large amplitude.

In the literature [5] a method of filtering the H_{02} wave is described, based on the fact that conditions arise in the waveguide that are unfavorable to the spreading of waves of this type. Thus, in the circular waveguide, dielectric planks are placed along its entire length (at a certain distance from each other). The practical realization of such a system is beset with considerable difficulties. In addition, because of the imperfection of existing dielectrics the losses of the main H_{01} wave in such a system will increase in comparison with the usual waveguide lines.

In the filter for H_{02} waves in a circular waveguide, proposed by us, filtration is performed by means of the transformation of this wave into unsymmetrical waves (basically into E_{12} , H_{12} , and H_{13} waves)¹, which, in their turn are damped by a ring-mode filter (Fig. 1). As can be seen from fig. 1, the filter consists of two basic parts: the transformer and ring filter. For transformation of H_{02} waves into unsymmetrical waves, the circular waveguide of radius R is divided into two semicircular waveguides by a metallic plate, placed along the diameter where the radius of one of the semicircular waveguides (the upper one on the figure) slowly decreases to the value R . At the output of the transformer the radii of the semicircular waveguides are again made equal and the metallic plate is sheared off. In the described unit the H_{02} wave is subdivided into two quasi- H_{02} waves in the semicircular waveguides, which then spread out in the latter with different phase velocities. In our case the change in the phase velocity in one of the semicircular waveguides is made at the cost of a decrease in radius ($R_1 < R$). In the general case one may change the phase velocity by placing a dielectric, ferrite or metallic pivot in one of the semicircular waveguides. At the output of the transformer the phases of the waves in the semicircular waveguides will be shifted by the angle

$$\alpha = (\gamma - \gamma_1) l_e,$$

where α is the phase difference between the quasi- H_{02} waves at the output of the semicircular waveguides: γ and γ_1 are the phase constants corresponding to the lower and upper semicircular

¹The percent content of nonsymmetrical waves at the output of the transformer depends on the ratio $2R/\lambda$. In the examined case, $2R/\lambda \approx 3$.

waveguides; l_e — is the equivalent length of that portion which has a decreased radius R_1 in accordance with transfers to this radius.

Choosing the length l_e in such a fashion that the phase difference α at the output of the semicircular waveguide is equal to π , we will obtain a field plot as shown in the center of the upper part of Fig. 1. During transfer to the circular waveguide this field plot is transformed essentially into E_{12} , H_{12} , H_{13} waves. For illustration of this process, in the upper part of Fig. 1 the transformation of the H_{02} wave into the E_{12} wave is shown.

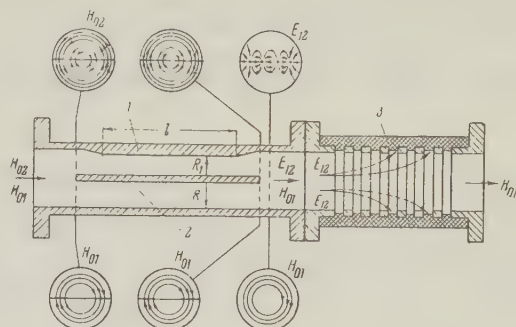


Fig. 1. Construction principle of the filter of H_{02} waves
1 - transformer; 2 - metallic plate; 3 - ring filter.

The H_{01} wave, propagating in the semicircular waveguides, is also dephased, although to a much lesser degree, since the difference in phase velocities in the semicircular waveguides is smaller for this wave than for the H_{02} wave. The dephasing of the H_{01} wave at the output of the unit also leads to formation of unsymmetrical waves in the circular waveguide (basically E_{11} , H_{11} , H_{12}) and consequently to an increase in losses. For removal of this phenomena the semicircular waveguides are interconnected by two rows of narrow transverse slits, placed along the maximum of the longitudinal H_{01} wave current in the metallic plate which separates the semicircular waveguides. Such a connection corrects the phase velocities of the H_{01} wave in the semicircular waveguides. At the same time, in the region of these slits the longitudinal current, formed in the plate by the H_{02} wave, is equal to zero.

Consequently, the connection between the semicircular waveguides is absent for this wave, and, thus the above considerations remain in force. In this way the described unit filters out the H_{02} wave, hardly influencing the propagation of the H_{01} wave (lower part of Fig. 1.).

For an experimental check of the above considerations a sample filter of H_{02} waves was constructed (Fig. 2.). Measurements were performed on a waveguide with a diameter of 25 mm; the difference between radii $R-R_1$ was 0.5 mm; the length of the transformer was 150 mm; the ring filter had approximately the same length. In the 8 mm range, with a bandwidth of the order of 5%, losses of the H_{02} wave in this unit were approximately 7-8 db. Losses of the H_{01} wave were only 0.14 db.



Fig. 2. General view of filter of wave

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ON H_{01} WAVE EXCITATION IN A CIRCULAR WAVEGUIDE

For the investigation of waveguide communication lines [1] H_{01} wave exciters are necessary in a circular waveguide with low losses. Since vacuum units in the centimeter and millimeter bands are designed for operation with rectangular waveguides, such an exciter must transform the H_{10} wave in a rectangular waveguide into the H_{01} wave in a circular waveguide. The best samples, described in the literature of transformers $H_{10}^{\square} \rightarrow H_{01}^{\circ}$ have losses of the order of 0.5 db. [2, 3]. Such losses are not always permissible, Thus, for

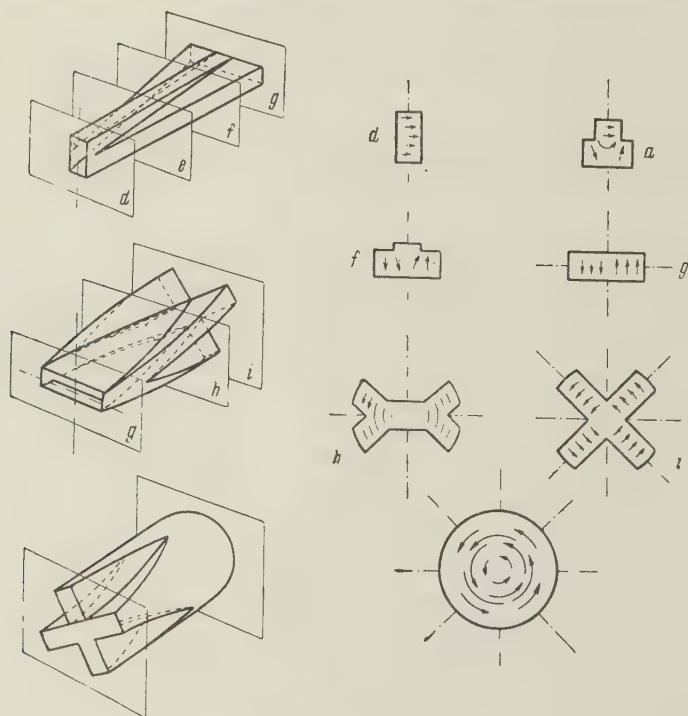


Fig. 1. Construction principle of transformer $H_{10}^{\square} \rightarrow H_{01}^{\circ}$

instance, in measuring devices, the losses in the line itself, which has a small length may turn out to be considerably smaller than this value.

Comparison of the different types of transformers has shown that most effective is the transformer described in the article [3]. The construction details of such a transformer are depicted in Fig. 1. The process of transformation of the H_{10} wave in the rectangular waveguide into the H_{01} wave in the circular waveguide is shown on the right side of the figure.

¹Drawings of the transformer were kindly sent to us by P. Marie.

If the dimensions of the transverse section are correctly chosen and if there is ideal symmetry of the device, waves of parasitic type will not be formed in this system. However, the creation of the complicated portion of the transformer (center figure) is bound with great technological difficulties. Spiral surfaces cannot be made sufficiently identical in practice, and symmetry is not achieved; consequently parasitic-type waves at the output of the transformer are formed.

Investigation has shown that losses in experimental sample transformers are essentially caused by the generation of parasitic waves in the circular waveguide. In order to decrease the losses it is necessary to increase the accuracy of construction of the center portion (transformer $H_{20}^{\square} \rightarrow \text{Quasi } H_{01}^{+}$) by simplifying its configuration.

In Figure 2 a transformer is shown in which the transfer from rectangular to cruciform waveguide is made with the aid of a device of simple components (sectioning of a cylindrical surface by planes).

Experimental samples of transforms $H_{10}^{\square} \rightarrow H_{01}^{\circ}$ (Fig. 3) had losses of the order of 0.25 db. in the 8 mm range with a 5% bandwidth; SWR is of the order of 1.1. At separate points of the band, losses were less than 0.2 db, which testifies to the possibility of a further decrease in losses in transformers of this type.

In conclusion I wish to express my gratitude to P. Marié for kindly submitting drawings of the transformer, and to Yu. I. Kaznacheyev for the organization of this work and for constant attention to it.

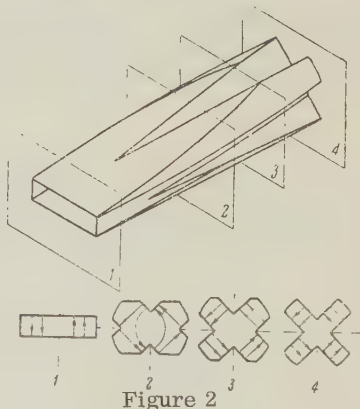


Fig. 2. Simplified configuration of transformer $H_{20}^{\square} \rightarrow \text{Quasi } H_{01}^{+}$



Figure 3

Fig. 3. General view of transformer $H_{10}^{\square} \rightarrow H_{01}^{\circ}$

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LETTERS TO THE EDITOR

ON A DIFFUSION EQUATION FOR A STATISTICALLY IRREGULAR WAVEGUIDE

In the article by M.E. Gertsenshtein and V.B. Vasilev [1] it is shown that the transformation of the probability density W of the coefficient of reflection of the wave r along the statistically irregular waveguide is described by the relation

$$\frac{\partial W}{\partial t} = \Delta W, \quad (1)$$

where t is the dimensionless length of the investigated region of the waveguide, Δ is the Laplace operator on the Lobachevsky plane.

However, because of incorrect interpretation of the Beltram coordinates, the authors [1] made an error during the determination of the operator and therefore obtained incorrect results.

In the present note the method proposed by M.E. Gertsenshteyn and V.B. Vasil'yev is an equation for a statistically irregular waveguide.

As noted in [1] each new irregularity leads to the linear rational transformation of the coefficient of reflection

$$r \rightarrow \text{sum}^{r_1} = \frac{r_1 + r_2 e^{i2\alpha}}{1 + r_1 r_2 e^{i2\alpha}}, \quad (2)$$

Preserving a unit circumference on the plane $r = x + iy$. The unit circle ($|r| \leq 1$) with the group motion (2) may be thought of as a Poincaré model of Lobachevsky's surface. The authors of the work [1] identified the x, y coordinates of the points on Poincaré's circle with the Beltram coordinates of Lobachevsky's surface in the determination of the Laplace-Beltram operator. In the Poincaré circle the metric form

$$ds^2 = \frac{(1-y^2)dx^2 + 2xy dx dy + (1-x^2)dy^2}{(1-x^2-y^2)^2} \quad (3)$$

is used or in the coordinates

$$\eta = \frac{1}{2} \ln \frac{1-y}{1+y}, \quad \varphi = \arctan \frac{y}{x} \quad (\text{where } r = e^{i\varphi}),$$

utilized in [1],

$$ds^2 = d\eta^2 + \text{sh}^2 \eta d\varphi^2, \quad (4)$$

The metric form (3) and, consequently, (4) are invariant with respect to transformation (2).

The invariant metric in the Poincaré circle (see [2], page 33), is given by

$$ds^2 = 4 \frac{dx^2 + dy^2}{(1-x^2-y^2)^2}. \quad (5)$$

In accordance with [5], Eq. (1) will be written as

$$\frac{\partial W}{\partial t}(x, y, t) = \frac{(1-x^2-y^2)^2}{4} \left[\frac{\partial^2 W}{\partial x^2}(x, y, t) + \frac{\partial^2 W}{\partial y^2}(x, y, t) \right].$$

The probability ΔP of finding x, y , in the interval $\Delta x, \Delta y$ is determined by the equality

$$\Delta P = W(x, y, t) \cdot \frac{4 \Delta x \Delta y}{(1-x^2-y^2)^2}. \quad (6)$$

Transferring to the variables ρ and ω and performing the integration of ω , we find

$$\frac{\partial W(\rho, t)}{\partial t} = -\frac{1}{2} \frac{\partial}{\partial \rho} \left\{ (1 - \rho^2)^2 W(\rho, t) \right\} + \frac{1}{2} \frac{\partial^2}{\partial \rho^2} \left\{ (1 - \rho^2)^2 W(\rho, t) \right\}$$

where

Equation (7) was obtained previously by a different method [3]. Its solution for a match at the output of the waveguide $(W(\rho, t)|_{t=0} = \delta(\rho)/\rho)$ is in the form [3]

where

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S. I. Al'ber, V.I. Bespalov
Submitted to editors on June 4, 1960

CONCERNING S.I. ALBER AND V.I. BESPALOV'S LETTER "ON A DIFFUSION EQUATION FOR A STATISTICALLY IRREGULAR WAVEGUIDE"

Concerning S.I. Alber and V.I. Bespalov's letter "On a diffusion equation for a statistically irregular waveguide" we report the following:

1. The error in our work [1] resulted from a scale multiplication in the coordinate. The metric invariant for (5), given in S.I. Alber and V.I. Bespalov's letter

$$d\Omega = \sqrt{\frac{1}{1 - \rho^2}}$$

by transformation into polar coordinates

becomes

Assuming, as in the work [1], that

$$\rho = \operatorname{th} \eta, \quad \eta = \frac{1}{2} \ln \frac{1+\rho}{1-\rho},$$

we obtain

$$ds^2 = 4 \operatorname{ch}^4 \eta \left[\left(\frac{d\eta}{\operatorname{ch}^2 \eta} \right)^2 + \operatorname{th}^2 \eta d\varphi^2 \right] = 4[d\eta^2 + (\operatorname{sh} \eta \operatorname{ch} \eta)^2 d\varphi^2] = [d(2\eta)]^2 + \operatorname{sh}^2 2\eta d\varphi^2.$$

In this way, we obtain the basic metric form in the work [1] - the formula (4) in Alber and Bespalov's letter

$$ds^2 = d\eta^2 + \operatorname{sh}^2 \eta d\varphi^2$$

in the coordinates

$$\eta = \ln \frac{1+\rho}{1-\rho}; \quad \varphi = \arctan \frac{y}{x},$$

where the η coordinates are twice as large as the η coordinates in the work [1]. (Correction published in the Journal "Theory of Probability", 1960, 5, 3, 376.)

2. The original method of solving the examined problem is used in the work of F.I. Karpelevich, V.N. Turtubalin, M.G. Shur "Limit theorems for the composition of probability distributions in planes and Lobachevsky space" (see "Theory of Probability", 1959 4, 4, 432.)

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M.E. Gerstenshteyn, V.B. Vasil'yev

REVIEWS AND BIBLIOGRAPHY

BOOKS ON RADIO ENGINEERING AND ELECTRONICS IN 1961

According to the plans of the publishers for 1961, there is envisioned the publication of a considerable quantity of books; monographs, textbooks, manuals, reference and scientific-popular literature on radio engineering, electronics and contiguous fields of learning.

Below, from the publisher's materials, is presented information on these plans (the title s of more than 300 books are given). The books are given with the number of pages, the quarto-volume size, the planned edition, the approximate time of publication, and a brief description.

STATE POWER PRESS

Textbooks and Manuals

Aleksandrova, A.T., et al. . . Technology of Equipment of Electrovacuum Manufacture 27 sheets, 8000 copies (3rd. quarter).

Principles of operation, construction are examined and certain calculations of the technological equipment used for the manufacture of specially massive types of electron vacuum devices are given.

Textbook for electron vacuum technical schools.

Kaganov, I.L., General Course on Commercial Electronics, 25 sheets, 25,000 copies. (2nd. quarter).

The main electron vacuum and semiconductor devices and circuits in which they are utilized are examined. The principles of operation are presented and the constructions of electronic, ionic and semiconductor valves and circuits, of controllable and uncontrollable rectifiers are described. Different types of electron tubes and transistors are examined, as well as amplifier circuits and pulse generators utilized in automation and calculating machines. Descriptions of phototubes and electron-beam devices, used in commercial electronics are presented.

Designed as a textbook for students of electrotechnical schools and faculties.

Katsman, Yu.A., Fundamentals of Theory and Analysis of Radio Tubes, Second edition, revised and enlarged, 29 sheets, 20,000 copies (2nd. quarter).

Questions on the design and analysis of cathodes, diodes, triodes, multielectrodes tubes, VHF tubes with electrostatic control, klystrons and magnetrons are examined.

Intended for students of electrotechnical and technical schools and faculties.

Katsman, Ya.A., Ptitsyn, S.V., Iorish, A.E., Fundamentals of technology of construction of electron vacuum devices, 25 sheets, 15,000 copies, (2nd. quarter)

A systematized description of the fundamental technological processes of electron vacuum units is presented. Metallurgical operations on electron vacuum manufacture, cathodes, ceramics, gas absorbers, glass production operations, assembly experimentation, control of finished production are examined.

Intended for students of electronics and radio engineering technical schools.

Collection of authors, under the edition of K.V. Shalimovaya, Special practical work on semiconductor devices, 27 sheets, 8000 copies (3rd. quarter)

Laboratory experiments; serving as addition to the series of lectures on semiconductor devices are described. The themes of the experiments cover physics of electronic semiconductors, the technology of semiconductor materials, methods of their investigation and experimentation, fundamental applications and operation in circuits of semiconductor devices.

Textbook for students specializing in the field of semiconductor electronics.

Lebedev, I.V., edited by N.D. Devyatkova, Technique and Equipment at Ultrahigh Frequencies, 35 sheets 10,000 copies, (3rd quarter).

The general problems of present electronics at ultrahigh frequencies and the basic types of electron vacuum units at UHF are examined: triodes, klystrons, magnetrons,

traveling wave tubes, resonance discharge tubes and others. Considerations of the construction of electron vacuum tubes are given and the prospects of their development are noted.

Intended as a textbook for students of power, electrotechnical and radio-engineering technical schools.

Tyagunov, G.A., Electron Vacuum and Semiconductor Devices, 38 sheets, 25,000 copies, (3rd. quarter).

The book is devoted to a systematic presentation of physics fundamentals and elementary theory of electronic, ionic and semiconductor devices. All forms of such devices are examined with special emphasis on questions concerning devices that can be utilized in radio engineering and electronics.

Intended for students of universities.

Scientific-Technical Literature. Monographs.

Agte, Vatssek, et al., translated from Czech, Tungsten and Molybdenum in Vacuum Tube Manufacture, 22 sheet, 8000 copies (4th quarter)

A metallic-ceramic method of tungsten and molybdenum manufacture, utilizable in the electron vacuum industry, is described.

Artim, A.D., Theory and Methods of Realizing Frequency Modulation, 12 sheets, 7000 copies (2nd. quarter).

Examined are: transmission of frequency-modulated oscillations through linear loops; formation of frequency modulation, phase modulation; methods of decreasing distortions in FM. Examples of the design of FM units are given.

Balabanyan, N., Synthesis of Electrical Loops, Translated from English, 23 sheets, 10,000 copies, (3rd quarter).

Questions on the synthesis of two-terminal and four-terminal networks consisting of reactive as well as of elements with losses are examined. The various methods of the construction of two-terminal and four-terminal networks with the given frequency characteristics of impedances, admittances or transfer functions are described.

Baranovskiy, Electron-Beam Tubes, 12 sheets, 8000 copies (2nd. quarter).

Principles of operation, elements of construction, technology of manufacture and control of receiver TV electron-beam tubes (kinescopes) are given, as well as of the most used tubes for oscillography and radio location.

A typical outfit, used in manufacture of electron-beam tubes in the Soviet Union is described.

Belov, F.I., Soloveychik, F.S., Questions on the Reliability of Radio Electronic Apparatus, 10 sheets, 1000 copies, (1st. quarter).

Survey of reports debated at the symposium on Reliability of Radio Electronic Apparatus, (USA, 1958).

Bliskunov, N.A., Kamenetskiy, I.Ya., Technology of Manufacture of Electron Vacuum Devices, part 3, 15 sheets, 10,000 copies (4th. quarter).

The technology of manufacture of vacuum-proof ceramics and insulation within tubes is presented. The assembly, cooking, and pumping of devices are examined.

Bron, O.B., Fields as Forms of Matter, 15 sheets, 10,000 copies (4th. quarter).

The history of the development of knowledge of the electromagnetic field is illuminated and the fundamentals of the question are presented. Consequences arising from present knowledge on fields are examined.

Buklet, V.O., et al., Assembly of Radio Apparatus, 2nd edition, revised, 22 sheets 40,000 copies, (4th quarter).

The assembly of various elements, circuits and of the complete sets of radio apparatus are examined. Methods of checking and controlling assembly are described. The fundamental applications of materials and instruments during assembly are given.

Varlamov, R.G., Design and Arrangement of Radio Electronic Equipment, 7 sheets, 10,000 copies, (2nd quarter).

General questions on the design of radio electronic equipment are examined, characteristics and certain recommendations are given; questions on the arrangements of functional loops and radio components and certain characteristics of radio electronic equipment are examined (volume, weight, and efficiency).

Veklich, et al., Technology of Manufacture of Glass for Electron Vacuum Industry. 15 sheets, 8,000 copies (1st quarter).

Technological assembly of charge is described, the components and physicochemical basis of glass cooking processes is presented, a description of methods of making glassware is described. The main forms of spoilage of glassware are described with the reasons for their formation and methods of removal. Methods of controlling glassware fabrication are also presented.

Ganulich, A.K. Electronic Units, 4 sheets, 15,000 copies, (2nd quarter).

A description of small calculating units of constant action, constructed from direct current amplifiers and designed for solution of various mathematical relations. Principles of operation of solving DC amplifiers operation as integrators, summers, scale and inverter sections are given, as well as the principles of operation of multiplier blocks and function generators.

Gartman, Photomultipliers, Translated from German, 13 sheets, 8000 copies, (1st quarter).

The essential peculiarities of photoelectronic multipliers and the elementary processes which occur in them are illuminated; applications of multipliers in the measuring technology.

Gitis, E.I., Converters for Electronic Digital Calculating Machines, 15 sheets, 15,000 copies, (2nd quarter).

Glebov, G.D., Absorption of Gases by "Active" Metals, 10 sheets, 8000 copies, (3rd quarter).

The absorption properties of "active" metals used as adsorbers in electron vacuum technology are examined. (barium, thorium, zirconium, and so on). The fundamental kinetic investigations of processes and mechanics of interaction of such metals with oxygen, hydrogen and other gasses at low and reduced pressures are presented, a comparative estimate is given of the effectiveness and reliability of the adsorbers.

A survey is given of the literature on questions of technology of fabrication and utilization of getters.

Golembo, Z.B., Application of Cybernetics in Electronics, 13 sheets, 10,000 copies, (3rd quarter).

The book is devoted to methods of electrotechnical analysis with the aid of numerical electronic machines.

Questions of intercommunication between mathematical logic, calculation mathematics and solutions of electrotechnical problems, applications of the mathematical apparatus of calculating machines, and the requirements on analytical methods are formulated.

Gurkin, L.S., Theory of Optimum Methods of Radio Reception, 20 sheets, 10,000 copies, (1st quarter).

In the book the vast material on the theory of optimum methods of radio reception is systematized and generalized.

Zaeadnyy, A.M., Harmonic Synthesis in Radio Engineering and Communications, 22 sheets, 7000 copies (1st quarter).

Precise and approximate methods of harmonic synthesis are given and examples are presented of the applications of these methods in the investigation of transient and stabilized processes.

Zelenskii, S.I., Mikhailov, K.V., (editors), Systems of Industrial Television, (collection of articles and papers from foreign material) 12 sheets, 10,000 copies (3rd quarter).

Kaplanov, M.R., Levin, V.A., Automatic Frequency Tuning, 35 sheets, 10,000 copies (4th quarter)

The classification of various systems of automatic frequency tuning employed in various radio engineering units, is examined, and many especially utilizable in practice circuits are presented. Present-day circuits of phase discriminators, gas-discharge tube and semiconductor units applicable in tuning systems are examined.

Karpikhin, V.V., Technology of measurements of electrical parameters of condensers. 10 sheets, 8000 copies (3rd quarter).

In the book mass electrical measurements are described. Besides measurements of paper and mica condensers, units for the measurement of ceramic, metallic, paper, glass, enamel and stiroflex condensers are examined.

Klyatskin, I. Sh., Brunov, B.Ya., Goldenberg, L.M., Tseitlin, L.A., Theory of the Electromagnetic Field., 25 sheets, 10,000 copies (3rd quarter).

The electromagnetic field of stationary charges, the stationary electric field and magnetic fields of constant current are examined. The basic equations for the electromagnetic

field are presented and methods of solution are given. The required information on such topics as plane electromagnetic waves, the surface effect, the onset of electromagnetic energy waveguides and cavity resonators is presented. A Primary attention is given to alternating and electromagnetic fields and to questions on the propagation of electromagnetic waves.

Kobyakov, N. P., Nikolaev, B. V., Nosov, B. M., Mechanization and Automation of technological Processes of the Manufacture and Assembly of Printed circuits., 10 sheets, 8000 copies, (3rd quarter).

Fundamental information on printed circuits, methods of manufacture and basic requirements and details of printed circuits, necessary for the mechanization and automation of technological processes, are presented. Descriptions of lathes and of the equipment for manufacture and assembly of printed circuits, their construction and operation principles are given. The elements of the construction of lathes and systems of control are examined.

Kraizmer, L. P., Systems for Storing Discrete information, 25 sheets, 5,000 copies, (1st quarter)

Technical systems for storage of information (memory devices, information storage devices and so on), the physical principles on which memory devices operate, basic technical design, characteristics and range of usage are presented.

Krasilnikov, N. N., The noise immunity features of television systems, 12 sheets, 5000 copies (2nd quarter)

The onset and structure of noise in television units are examined. The influence of noise on the resolution capacity of the television system is analyzed and norms for noise-proofing television systems are given. An engineering method of calculating the noise-proof feature of television units is presented and concrete measures are recommended to raise it. The technique of noise measurements in television is described.

Krasovskiy, A. A., Pospelov, G. S., Fundamentals of Automation and of Technical Cybernetics, 40 sheets, 15,000 copies (2nd quarter)

In the book a systematic presentation of the applied theory of certain elements of automatic units, processes of automatic regulation and questions on technical cybernetics is given.

The fundamentals of the theory of discrete and linear nonstationary systems are presented.

Considerable attention is given to new interpretation of information and entropy in closed systems of automatic control.

Kuzmenko, M. I., Sivakov, A. R., Semiconductor Direct-Current Converters, 8 sheets, 10,000 copies (4th quarter)

The basics of the theory and method of design of direct current at low voltages converted into direct current at high voltages are given.

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The basic state of cybernetics and of the theory of controlling machines, and the theory of electronic relay protection are briefly given. The main questions on semiconductory physics characteristics and experimental data of semiconductor diodes and triodes are elucidated. The principles of construction of relay protection circuits made from semiconductor elements are described

Nechaev, G. K., Udalov, N. P., Semiconductor Thermal Resistances in Automation Circuits. 5 sheets, 15,000 copies (1st quarter)

The parameters and characteristics of semiconductor thermal resistors are described brief details on samples given out by industry are given. Certain properties of chains with thermal resistors are given.

Partridge, G., Electronic Measuring Devices, transl. from English, 20 sheets, 15,000 copies, (2nd quarter)

The principles of operation of various electronic devices for measuring electrical and nonelectrical values in the frequency range up to 1 Mc are described. Specific circuits and the peculiarities of operation of many devices are examined.

Parnes, M. G., Mechanization and Automation of the Manufacture of Radio Components.,

18 sheets, 10,000 copies (2nd. quarter)

A survey of the present-day state of mechanization and automation of the manufacture of radio components is given and the corresponding equipment is described. An analysis of especially useful methods of mechanization and automation of the production of radio components is presented and the paths of technical progress in this field are described. Questions on the economic effectiveness of the introduction of new techniques are examined.

Semiconductor Devices with Negative Resistance, collection of translated articles, 17 sheets, 10,000 copies (1st quarter)

Articles are presented on theory, technology of manufacture and construction of new semiconductor devices in whose static or dynamic volt-ampere characteristics there is a region of negative resistance. A description is made of such devices, their parameters and fields in which they may be used.

Rabkin, L.I., Epshteyn, O.Sh., Soskin, S.A., Technology of Magnetic semiconductors 23 sheets. (2nd. quarter) 5000 copies.

Deals with Soviet and foreign experiments in nonmetallic ferromagnet production. Gives characteristics of starting materials and methods of testing them. Technological peculiarities of ferrite preparation in relation to chemical composition are considered. Basic and auxiliary equipment both for production of ferrites and parts made from them are described. The most important magnetic characteristics of various ferrites in direct and alternating fields are given.

Radio Interference from Electric Power Lines (a review), 3 sheets, 5000 copies (2nd quarter)

Theory of propagation of radio waves along power lines is presented. Laboratory investigations of corona discharges and radio disturbances and measurement of interference under field conditions are described. Data on the latest measuring apparatus is presented.

Samokhvalov, M.M., Germanium Diffusion Triodes, 10 sheets, 8000 copies (2nd quarter)

Experience in working with and using diffusion triodes is set forth; their parameters and characteristics are considered and calculation methods presented.

Semenov, Yu.A., Production of Heaters for Vacuum-Tube Instruments, 12 sheets, 8000 copies (3rd quarter)

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Random noise generators, their construction and use is considered. Primary noise sources are described, and a comparative appraisal is made of their employment in noise generators. Questions of calibration and control from the point of view of output voltage and distribution law are discussed; arrangements of instruments used to study distribution laws of random processes are described.

Fainshteyn, S.M., Role of the Surface State in the Production of Semiconductor Devices, 8 sheets, 8000 copies (2nd quarter)

Concerns increasing the reliability of semiconductor instruments; necessary materials for investigation of the magnitude of the surface states on transistors of fixed parameters are set forth.

Tsarev, B.M., Calculations and Construction of Vacuum Tubes, 2nd printing, revised and enlarged, 30 sheets, 10,000 copies (2nd quarter)

Basic calculations and construction are considered. New chapters are included in the second edition, embracing design of electronic instruments, initial currents in diodes and multigrid tubes, inherent tube noise and glass- and ceramic-metal welds.

Spaeter, Electronic Television, transl. from German, 60 sheets, 20,000 copies (4th quarter)

Basic physical phenomena employed in television are presented; the constituent parts, transmitting camera, optics and radio apparatus (video amplifier, television signal transmitter, sound accompaniment, auxiliary apparatus, studio technique), image and sound receivers, scanning and synchronization, basic blocks of television and color TV fundamentals are considered.

Shteyn, N.I., Harmonic Oscillators, 27 sheets, 8000 copies (1st quarter)

Various circuits for generation of low, high and ultrahigh frequency harmonics are considered, with theory of operation and calculations.

Espe, Vacuum-Tube Technology, transl, from Czech and German, 55 sheets, 10,000 copies (3rd quarter)

Assessing the properties of materials used in tube production.

Esterkin, M.S., Repair of Electronic Apparatus, 12 sheets, 15,000 copies (2nd quarter)

Characteristic faults and their correction, testing and tuning methods are described; handbook data for the most common Soviet instruments is reproduced for meters, oscillographs rectifiers and oscillators. Principles of switching circuits, voltage charts, wiring and location diagrams are presented.

The book may serve as a reference for radiotechnical instruments.

Effective Thermionic Cathodes (collection of translations under editorship of B.N. Popov and A.R. Shul'man) Number 3, 25 sheets, 5000 copies (3rd quarter)

The issue contains the most important articles published recently in leading foreign journals on the subject of the physics and technology of effective cathode production. Articles seek to contribute solutions to problems of oxide cathodes used as basic elements in many forms of modern vacuum tube instruments.

Handbooks and Reference Material

Broide, A.M., and Tarasov, F.I., Handbook for Vacuum-Tube and Semiconductor Devices, 2nd edition, enlarged, 20 sheets, 100,000 copies (3rd quarter)

Contains reference material on Soviet and certain types of foreign receiver-amplifier tubes, kenotrons, low and medium power generators, kinescopes, oscilloscope tubes, voltage and current stabilizers, semiconductor diodes and transistors.

Radiotechnical Handbook, transl. from German, 2 volumes, 70 sheets, 60,000 copies (3rd quarter)

Basic contents are formulas, tables and graphs of a radio engineering nature primarily concerned with communication. Individual chapters deal with circuit elements and oscillatory circuits, circuit theory (lines, filters, coaxial cables, waveguides), antennas for different bands, electronics, electronic tubes and instruments. Basic facts in theory of amplification and theory of low-frequency power and voltage amplifiers, modulators and demodulators, theory of radio reception and generation of waves of various frequencies; the propagation of radio waves and theory of radio-technical measurements are presented.

Fink, D., Handbook of Television Technique, transl. from English, 100 sheets 20,000 copies (3rd quarter)

Basic theory is presented along with formulas for calculation, reference data and basic parameters of transmitting, receiving, and auxiliary equipment for cathode-ray tubes.

Churabo, D.D., Basic Construction of Radiotechnical Instruments, 35 sheets, 12,000 copies (4th quarter)

Reference data, standard technological data and methods for fashioning radio-technical parts from ceramics, plastics and metals are presented; recommendations are made for construction of devices to be used in tropical conditions, and certain other special parts and instruments are discussed.

Popular Science Literature

In the series, "Radio Library for the Masses", the publication of 50 books, involving a total of 300 sheets is planned.

The books of this series are intended for beginners and advanced amateurs, high school and technical students, technicians and young engineers.

The following books from the planned catalog may be mentioned:

Barsukov, F.I., Remote Radio Control, 6 sheets, 30,000 copies (3rd quarter)

Batrakov, V.A., and Bogatyrev, V.I., Electronic Calculator for Logico-Information Solutions, 2 sheets, 40,000 copies (2nd quarter)

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- Boguslavskiy, S.A., Collected Works on Physics, under editorship of V.K. Semenchenko, 22 sheets, 5,000 copies (1st quarter)

Boguslavskii was one of the most outstanding theoretical physicists active in the years immediately preceding the Revolution and the first few following establishment of the socialist state. The present edition seeks to acquaint Soviet physicists with his work, much of which, due to his rich imagination, and fine and thorough presentation, still retains its value.

- Bohm, D., Quantum Theory, transl. from English under editorship of S.V. Bonsovskii, 45 sheets, 20,000 copies (2nd quarter)

Nonrelativistic quantum mechanics of the well-known American theoretical physicist D. Bohm. Gives a penetrating and original analysis of the basic problems in the field.

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- Sanin, A.A., Electron Instruments in Nuclear Physics, 35 sheets, 20,000 copies, (3rd quarter)
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- Sokolov, A.V., Optical Properties of Metals, 25 sheets, 10,000 copies (2nd quarter)
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- Hammond, P., Feedback and Its Applications, transl. from English. 17 sheets, 10,000 copies (3rd quarter)
- Gives variform applications of feedback in electronics and automation. A simple, systematic presentation of fundamentals of automatic regulation theory. Presents typical circuits for amplifiers used in servosystems and electronic modelling setups. Methods of stabilizing amplifiers are given. Much attention is given to analysis of nonlinear automatic control systems by a phase density and harmonic balance approximation method.
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A review of the state of contemporary computer technology and its role in automation. Computers are considered devices for treatment and transformation of information; theoretical question are set forth.

Sproul, R., Modern Physics for Engineers, transl. from Eng. under edit. B.N. Finkel'shteyn, 26 sheets, 35,000 copies (2nd quarter)

Basic questions; gives outline of fundamental progress in physics made in last fifteen years (electron optics, television, semiconduction, isotopes, power from atomic energy, etc.)

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Angerer, E., Technology of Physical Experiments, transl. from German, under edit. K.P. Yakovlev, 27 sheets, 50,000 copies (1st quarter)

English-Russian Electrotechnical Dictionary, second edition, Compiled by Geiler, L.B., and Dozorov, N.I., 55 sheets, 20,000 copies (1st quarter)

The dictionary contains 40,000 terms covering electric power, machine and apparatus construction, wire communication and radio technology

Group of authors under edit. of K.P. Yakovlev, Brief Physico-technical Handbook, Vols. 1 - 3, 90 sheets, 200,000 copies (4th quarter)

Vol. 3 covers technical thermodynamics, electronics technology and radio engineering.

Koshkin, N.I., and Shirkevich, M.G., Handbook of Elementary Physics, under edit. D.I. Sakharov, 2nd edition 10 sheets, 200,000 copies (1st quarter)

Includes basic division of physics: mechanics, vibrations and waves, molecular physics, electricity, optics and atomic physics.

Much attention is given to properties of new materials (semiconductors, ferroelectrics, ferrites, plastics, etc.)

International Dictionary of Electronics and waveguides; Russian section compiled by Bargin, B.G., and Buchinskiy, A.S., 20 sheets, 20,000 copies (4th quarter)

Contains more than 2,000 entries on vacuum tubes, cathode-ray tubes, ion devices, UHF, photoelements, secondary-electron multipliers, vacuum materials, rectifiers and waveguides.

International Dictionary of Television, Radar and Antennas; Russian section compiled by Bargin, B.G. and Buchinsky, A.S., 30 sheets, 20,000 copies (4th quarter)

2400 entries concerning physical bases of television, radar and associated apparatus, outfitting of television studios, color TV, and antennas of all ranges.

International Nuclear Dictionary; Russian section compiled by Voskoboinik, D.I., 30 sheets, 20,000 copies (3rd quarter)

4000 terms connected with theoretical and experimental nuclear physics, reactor physics and radiobiology. Includes some terms from overlapping areas - metallurgy, mining chemical technology, etc.

The three dictionaries above, in seven languages (English, Russian, French, Spanish, Italian, Dutch, and German), have indexes for each of the languages and may be used in various language combinations (e.g., as a Russian-English, Russian-German, English-German dictionary, etc.)

German-Russian Radiotechnical Dictionary, compiled by Kozlov, V.F., and Pozen, N. L. under edit. O.B. Lur'e, 40 sheets, 30,000 copies (3rd quarter)

Contains about 30,000 entries in theoretical radio technology, radiation, propagation and reception of radio waves, antennas, ultrahigh frequencies, pulse technique, radar, radio navigation, communication, electron and ion emission, vacuum tubes, cathode ray instruments, semiconductor devices and other subjects in radio engineering and electronics.

Smolyanskii, M.L., Tables of Indefinite Integrals, 5 sheets, 100,000 copies (2nd quarter)

About 2000 integrals included.

French-Russian Nuclear Dictionary, compiled by a staff under editor Voskoboinik, D.I., 30 sheets, 15,000 copies (3rd quarter)

Contains about 30,000 entries.

Childs, U., Physical constants, transl. from Eng., 5 sheets, 100,000 copies (2nd quarter)

Represented as a complete compilation of tables of the basic physical constants; includes nomograms to aid in making the most frequently encountered calculations; a handy book for students.

FOREIGN LITERATURE PRESS

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Works of foreign authors concerning theory and applications of elliptical polarization to radio technology, in particular, antenna construction. Many basic premises in theory of antennas, feeder technology, etc., are derived from the most common type of polarization, i.e., elliptical; latest construction of polarization antennas is described.

Bohr, N.A., Atomic Physics and Man's Knowledge (New York, 1959) transl. from English by V.A. Fok, 8 sheets (3rd quarter)

Collected articles of recent years from the pen of the outstanding contemporary theoretical physicist, Niels Bohr. The author not only gives his understanding of modern problems in atomic physics but also clarifies his own philosophical beliefs.

In particular, he rejects scepticism and agnosticism and attempts to define the philosophical tenets associated with the so-called "Copenhagen interpretation" of quantum mechanics.

Bucholz, G., Electric and Magnetic Field Calculations (Berlin, 1957) transl. from Ger. 35 sheets (2nd quarter)

A guide to modern precision methods for calculating complex electrical and magnetic fields.

Van der Zil, A., Fluctuation Noise in Semiconductors, (New York, 1959) transl. from English, 12 sheets (4th quarter)

The monograph gives a critique and systematic presentation of theory of noise in semiconductors; acquaints reader with results achieved in the field and with unresolved problems.

Topics in the Quantum Theory of Irreversible Processes (collection), 18 sheets (2nd quarter)

Concerned with new field of irreversible processes in physics and direct calculation of kinetic constants of such processes as electroconductivity, diffusion, etc.

Grenander, U., Random Processes and Statistical Deductions (Stockholm, 1950) transl. from English, 7 sheets, (1st quarter)

Articles by the well-known Swedish mathematician on statistical deduction from data on a single random process. This subject is never discussed in monographs on theory of random processes or applications but is extremely significant to many important technological problems (detection of signal in presence of background noise, etc.)

Appended to the translation is an article by A. M. Yaglom, giving a review of findings in random-process statistics during the last ten years.

Moving Plasma (Collection), Transl from Eng. 30 sheets (2nd quarter)

Methods of creating moving plasmas, reactions with magnetic fields and magnetohydrodynamic processes are also considered. The contemporary state of the art is presented.

Zinger, G., Masers, (New York, 1959), transl. from Engl. 10 sheets (3rd quarter)

Devoted to a systematic presentation of the new field of quantum amplifiers and oscillators, based on the use of the special properties of certain gases and paramagnetic crystals.

Ingram, D., Paramagnetic Resonance and its Application to the Study of Free Radicals (London, 1958) transl. from English, 21 sheets, (1st quarter)

Gives the present state of electron paramagnetic resonance and describes applications to investigation of various systems of free radicals.

Investigations of the Upper Atmosphere Using Rockets and Satellites (collection) transl. from English, 25 sheets (3rd quarter)

Includes the latest, though basically American, results of research in the upper atmosphere by rockets and satellites, reported at the Fifth Assembly of the International Committee for the IGY, in autumn 1958, and also published very recently in certain journals.

Karrel, G., New Circuits for Semiconductor Instruments (New York, 1959), transl. from English, 25 sheets, (3rd quarter)

Presents a detailed description, with all necessary data, of a large number of diverse circuits; also considers semiconductor applications to telemetric systems for use in satellites and rockets.

Quantum Paramagnetic Amplifiers (coll.) transl. from English, 17 sheets, (1st quarter)

Concerned with quantum mechanical paramagnetic amplifiers for weak radio signals, almost completely free of inherent noise. Includes articles on physical principles of operation (low-temperature paramagnetic resonance), theory of amplification and constructions of the devices with specific circuits and characteristics, and technology of operation.

Collection of articles by foreign authors on various topics in the general theory of control systems.

In the first section are grouped popular articles on applications of mathematical logic, probability theory and theory of games to analysis and determination of the most effective solutions to problems. In the second and third sections material is presented on the latest calculator, the "Stretch" which performs almost a million operations per second, results of research on reliability of automated devices, theory of self-correcting codes and transport network theory.

Oscillatory Processes in Plasmas and their Use in Amplification and Generation of Ultrahigh Frequencies (coll), 15 sheets (3rd quarter)

Articles on various problems in plasma physics, important to the further development of new types of UHF devices (oscillators, amplifiers, etc.) which have appeared in the last five years.

Presents works bearing on the questions of excitation of plasma waves, reactions of plasma with electron beams and mechanism of propagation of waves in plasma.

Cross, A., Introduction to Practical Infrared Spectroscopy (London, 1960) transl. from English, 6 sheets, (2nd quarter)

Makes a practical handbook on IR spectroscopy. Considers most essential theoretical questions, practical measurement methods and applications.

Loev, M., Theory of Probability (New York, 1960) transl. from Eng. 35 sheets.

This is a systematic course in modern probability theory.

Luce, R.D. and Raiffa, H., Games and Solutions; and Introduction and Review (New York, 1957) transl. from Eng. 38 sheets, (1st quarter)

Devoted to mathematical theory of games and applications with explanations of

classical methods of analysis; includes various aspects of theory of games with nonzero sums, and solutions involving indeterminates.

Magnetic Properties of Metals and Alloys (Cleveland, 1959) 18 sheets

A translation of survey reports made at the seminar in Cleveland, (USA) by the most outstanding American specialists in magnetism and magnetic materials. Touches on some of the important problems in modern physics of magnetic phenomena and describes latest foreign advances in this important field (high-frequency magnetic alloys, ferrites, ferromagnetic resonance, etc.).

Moss, G., Optical Properties of Semiconductors (London, 1959) transl. from English, 17 sheets, (1st quarter)

Monographs connected with optical and photoelectric properties of semiconductors. Theory of optical properties of semiconductor crystals and research methods and results on important investigations of all forms of semiconductor crystals (Ge, Si, sulfide, halide, etc) are discussed.

Noble, B., Application of the Wiener-Hopf Method to the Solution of Partial Differential Equations (London, 1958) transl. from English, 14 sheets, (3rd quarter)

Shows application of the well-known Wiener-Hopf method to boundary value problems in partial differential equations, extended to the solution of a defined class of integral equations; considers problems in diffraction, wave theory, etc.

Novaku, V., Introduction to Microscopic Electrodynamics (Bucharest, 1955) transl. from Rumanian, 22 sheets, (3rd quarter)

A basic course for students in microscopic electrodynamics (electronic theory and related portions in the theory of relativity).

Parametrons (coll) transl. from Japanese, 25, sheets

A collection composed of articles published in the Japanese journal "Electronics" since 1959. Acquaints the reader with principal phenomena and main lines of research on parametrons being pursued at present in Japan.

Semiconductors, under edit. Henney (New York, 1959) transl. from English. 50 sheets

Deals with chemistry and physical chemistry of semiconductors.

Production and Investigation of High-Temperature Plasmas (coll) transl. from English 20 sheets (4th auarter)

Includes works from the Conference on Ultrahigh Temperatures (USA, 1958). The reports cover experimental and theoretical subjects in the field. Particular attention is given to use of electric discharges in obtaining high temperatures.

Radio Astronomy (coll). 1959 transl. from English, 57 sheets, (2nd quarter)

Reports from the Paris Symposium on Radio Astronomy, (July, 1958)

Richards, R., Elements and Circuits of Digital Computers (Princeton, 1958) transl. from Eng., 27 sheets (2nd quarter)

Gives American experience in science and technology of this field. Memory devices (electronic-beam, ultra-acoustic and ferrite) and transistor circuits are described. Operation of such new elements as cryotrons, special vacuum and gas instruments, decade counter tubes, etc., are also considered.

Smith G. and Wayne, G., Ferrites (Amsterdam, 1959) transl. from English, 26 sheets

Gives magnetic properties of ferrites, methods of preparation and research on behavior in alternating fields, etc.

Contemporary Problems in Biophysics (coll) vol. 2. transl. from English, (3rd quarter)

Considers the effect of radiation on living organisms, mechanisms of transfer and perception of irritation by sensory organs, muscles, etc.

Contemporary methods of experimental research are heavily drawn on for solution of these problems and are applied in biology exactly as in chemistry and physics; the extremely interesting methods of information theory are also utilized.

Stuart, G., Theory and Synthesis of Electrical Networks (New York, 1958) transl. from English, 30 sheets, (4th quarter)

Considers problem of constructing electrical devices with given optimum characteristics. Gives new solutions, with exception of difficult variation method. May be used as a textbook on technology of network synthesis.

Troup, C., Molecular Amplifiers and Oscillators (London, 1959) transl from English, 5 sheets, (2nd quarter)

This book by the well-known British scientist is the first foreign monograph on

theoretical questions in research and application of masers.

Tunnel Diodes (coll.) transl. from English, 7 sheets (2nd quarter)

Articles on use and application of tunnel diodes.

Guidance and Telemetry, No. 4. (coll.) 15 sheets

Collection devoted to manufacture and application of individual parts (transducers, amplifiers, commutators, etc.) and telemetric devices for industrial, military, and satellite purposes and biological research. Includes the most interesting material from the National Conference on Telemetry which met in USA in 1958.

Plasma Physics and Magnetohydrodynamics (coll.) 20 sheets (2nd quarter)

Original work of foreign scientists engaged in investigation of hot plasmas and magnetohydrodynamics with the aim of producing a controlled thermonuclear reaction.

Finkelburg, V. and Mekker, G., Electric Arcs and Thermal Plasmas (Berlin, 1956) transl. from German. 15 sheets, (2nd quarter)

Sums up results of many years' work by scientists in a score of lands in the field of electric arcs and thermal plasma.

Franz, V., Disruptive Discharges (Berlin, 1956) transl. from English. 12 sheets (3rd quarter)

Considers latest scientific data on physical processes in electric discharge, experimental methods and results, and real dielectrics and their characteristics.

Chemistry of the Solid State, under edit. Garner, K. (New York, 1955) transl. from English, 25 sheets, (2nd quarter)

Presents basic theory of solid state, Among topics are: chemistry of dislocations, theory of lattice defects, action of light on solids, questions concerning surfaces of solids, semiconductors and magnetochemistry, theory and classification of solid-state processes, etc.

Holm, R., Electrical Contacts (Berlin, 1958) transl. from English 40 sheets (2nd quarter)

Sets forth modern concepts in theory of electrical contacts; explains in detail physical processes accompanying operation.

Honigman, G., Growth and Shape of Crystals (Darmstadt, 1958) transl. from German, 10 sheets (2nd quarter)

Gives contemporary scientific representation of processes of formation and growth of crystals; describes basic methods of growth, experimental methods and observations on growth and form of various types of crystals.

Shapiro, I., Calculation of the Trajectory of a Ballistic Missile from Given Radar Observations (New York, 1958) transl. from English, 15 sheets (1st quarter)

Presents several practical (finite and statistical) methods for determining the trajectory of a missile or satellite from data received at radar stations. Problem is solved both for a stationary and a rotating earth. Several methods are compared as to their accuracy and suitability for digital computers.

Shimoni, K., Theoretical Electrical Technology (Berlin, 1956) transl. from German, 40 sheets

The book sets forth the most complicated problems in theoretical electronics (network and field theory), questions involving the propagation and radiation of electromagnetic waves.

Experimental Studies of Circumterrestrial Space (collection) transl. from English, 20 sheets (4th quarter)

Reports from the Symposium on Rocket and Satellite Exploration of Space held in the USA, 1959. Discusses potentialities and experimental difficulties, and methods and apparatus for detailed studies.

Electron Spin Resonance in Semiconductors (collection) 16 sheets (3rd quarter)

Deals with paramagnetic electron resonance in semiconductor crystals.

Yager, S., Structure and Energy processes in the Sun's Atmosphere (Berlin, 1959), transl. from English, 33 sheets (4th quarter)

This book by the Dutch astrophysicist contains an exhaustive presentation of the present state of our knowledge concerning the structure, composition and properties of the solar atmosphere, the three basic divisions - photosphere, chromosphere and corona - and the effect of solar activity on earthly processes (cosmic rays, polar auroras, radio-wave propagation, etc.) are considered.

ACADEMY OF SCIENCES, USSR, PRESS
Scientific Literature. Monographs

Anan'yeva, A.A., Ceramic Sound Receivers (Acoustic Institute of the Academy of Sciences, (USSR) 8 sheets, 3,000 copies (2nd quarter)

Describes properties of polarized barium titanate ceramics and other types developed by the Institute.

Atmospheric Turbulence (Institute of Atmospheric Physics, Academy of Sciences, USSR) 22 sheets, 3,000 copies (4th quarter)

A collection of reports from the Conference on Atmospheric Turbulence Research (Feb., 1960). Covers theory of atmospheric turbulence, methods and experimental studies, and propagation of radio and sound waves in turbulent air.

Topics in Terrestrial Magnetism (Trudy Institute of Terrestrial Magnetism, Radiowave Propagation and the Ionosphere, Academy of Science, USSR) No. 18, (28) 18 sheets, 4000 copies (3rd quarter)

Collection devoted to analysis of geomagnetic disturbances and theories of origins.

Prediction of the State of the Ionosphere and the Propagation of Radio Waves (Trudy Institute of Terrestrial Magnetism, Radio-Wave Propagation and the Ionosphere) No. 19 (29) 12 sheets, 5000 copies (3rd quarter)

Collection devoted to long-term and short-term radio forecasting, both of theoretical and experimental nature.

Problems in the Construction of Electronic Guidance Devices, Academy of Sciences, USSR, 12 sheets, 10,000 copies (3rd quarter)

Considers latest pulse and potential semiconductor circuits and analyzes possibilities of use of traveling-wave tubes; in waveguide technology. Deals with construction of memory devices with ferrite cores, magnetic ribbons and drums; describes devices for transforming information.

Studies in Spectroscopy and Luminescence (Trudy P.N. Lebedev Physics Institute, Academy of Sciences, USSR) vol. 15, 20.5 sheets, 3000 copies (2nd quarter)

Includes 3 dissertations defended at the Institute on spectroscopy (method of calculating single electron and complex-atom wave functions, excitation of spectra by spark discharge, and spectra in gas discharges) and one on luminescence. There is a bibliography on spectroscopy.

Artificial Earth Satellites, Nos. 6-10, 45 sheets 20,000 copies (2nd quarter)

A collection describing results of investigations with satellites.

Katys, G.P., Automatic Control of Nonstationary Parameters and Parametric Fields. (Institute of Automation and Remote Control, Academy of Sciences, USSR), 11.5 sheets 8000 copies (1st quarter)

Studies of continuous and discrete systems of automatic control in nonstationary fields. Considers theoretical problems in determining optimal parameters (number of lines, frame frequency) for different types of scanning.

Katzenelenbaum, B.Z., Theory of Irregular Waveguides with Slowly Changing Parameters (Institute of Radio Engineering and Electronics, Academy of Sciences, USSR) 15 sheets, (4th quarter)

Korablev, L.N., Cold-Cathode Tubes (P.N. Lebedev Physics Institute, Academy of Sciences, USSR) 7 sheets, 10,000 copies (1st quarter)

Gives properties of cold-cathode tubes, particulars of their operation, advantages compared to vacuum tubes and semiconductors, methods of employing them and apparatus and applications to various technological fields.

Lebedev, D.S., Transfer of Information over Communications Systems (Laboratory for Information-Transfer Systems, Academy of Sciences, USSR), 7 sheets, 5000 copies (2nd quarter)

Presents modern information theory in its application to communication systems. Considers statistical coding, raising of noise immunity and effectiveness of communications. Gives methods for finding the optimal parameters of such systems.

Selected Topics in Theoretical Physics (Trudy P.N. Lebedev Physics Institute, Academy of Sciences, USSR), vol. 16, 20 sheets, 3000 copies (3rd quarter)

Collection takes up multiparticle statistical theory and certain theoretical questions in nuclear physics and radiation theory.

Problems in Information Transmission, No. 8, Construction of Relay Circuits (Laboratory for Information-Transfer Systems, Academy of Sciences, USSR) 9 sheets, 5000 copies (2nd quarter)

Gives basic construction of contactless devices for synthesis of relay-contact circuits. Considers construction of contact circuits and syntheses of contactless relays, relays with parametric response, and multivalued logics.

Proceedings of the First International Congress on Automatic Control, in 6 volumes (National Committee on Automation, USSR. Institute of Automation and Remote Control, Academy of Sciences, USSR) 320 sheets, 60,000 copies (4th quarter)

Reports from the Congress (June-July, 1960, Moscow) on automation in various fields of human endeavor (industry, transportation, communication, etc.). Involves theory of automatic control, technical means, and applications.

Feynberg, E.L., Radio Broadcasting over the Earth's Surface, (P.N. Lebedev Physics Institute, Academy of Sciences, USSR), 35 sheets, 7000 copies (2nd quarter)

The monograph considers conditions of radio-wave propagation as functions of earth's surface characteristics and other factors.

Computer Elements (Institute of Precision Mechanics and Computer Technology, Academy of Sciences, USSR), 12 sheets, 3000 copies (3rd quarter)

Collection of articles on research and development of various new elements, parts and circuits in computer art.

Scientific Bibliography

Scientific Literature on Scattering of Light and Infrared Spectroscopy, vol. 1, 40 sheets 2500 copies (1st quarter)

Includes Soviet and foreign literature from 1928 to 1940.

Petukhova, M.S., Cosmic Rays, (P.N. Lebedev Physics Institute, Academy of Sciences, USSR) 24 sheets, 2500 copies, (3rd quarter)

A bibliographical index of cosmic-ray literature of 1956-1960. Includes most recent works on rocket and satellite research.

Popular Science Literature

Aleksandrov, S.G. and Fedorov, R.E., Soviet Satellites and Space Rockets, 2nd edition, enlarged, 16 sheets, 30,000 copies (1st quarter)

Covers construction, launching and trajectory of satellites and space rockets; presents research results obtained with them.

Bogatov, G.B., Terrestrial and Space Television, 5 sheets, 150,000 copies, (3rd quarter)

Speaks of television applications, physical processes and phenomena used in TV and operation of TV hookups

Bul, B.M., and Bogdanov, S.V., Ferroelectrics, 5 sheets, 75,000 copies (4th quarter)

About ferroelectrics and their use.

Gubkin, A.N., Electrets, 5 sheets, 75,000 copies (3rd quarter)

This brochure speaks of electrets, progress in their study and practical uses.

Kulebakin, V.S. and Nagorskii, V.D., Semiconductors in Automation, 10 sheets, 75,000 copies (4th quarter)

Properties and applications of semiconductors in automations.

Rozenblatt, M.A., Contactless Magnetic Controlling Devices, 7 sheets, 30,000 copies (4th quarter)

Properties and applications of contactless magnetic devices.

Sagdeev, R.Z., Plasma Physics, 7 sheets, 100,000 copies, (2nd quarter)

Discusses this new, rapidly developing field and plasma applications in electronics instruments, etc.

Smolenskiy, G.A., Ferrites, 4 sheets, 50,000 copies, (4th quarter)

Acquaints the reader with achievements in research and ferrite applications.

Shchennikov, V.V., Electronic Computers, 6 sheets, 100,000 copies (4th quarter)

Brochure on construction and principles of operation of these devices.

"Sovetskoye Radio" Press

Textbooks and Reference Material

Gutkin, L.S., Lebedev, V.S. and Siforov, V.I., Radio Receivers, Part I, under edit. V.I. Siforov, 34 sheets, (3rd quarter)

Takes up the amplification, detection and conversion of moderately high frequencies by vacuum-tube and semiconductor instruments, transient processes and noise in radio and UHF cascades. Special attention is paid to latest theory and technology of radio reception. Gives theory of optimal reception in presence of noise.

This book is the first part of a textbook for radio engineering trade schools.

Drabkin, A.L. and Zuzenko, V.L., Antenna-Feeder Construction, 40 sheets, (2nd quarter)

Presents basic theory of antennas, antennas with linear currents (symmetrical vibrators and vibrator systems, wire antennas of different bandwidths) and associated feeder systems. Considers antennas with surface currents (horn, lens, mirror, slot, and dielectric antennas with rotational polarization) and UHF feeder systems. Gives methods for measuring antenna-feeder parameters. May be used for courses in antenna-feeder construction.

Lur'e, O.B., Videofrequency amplifiers, 2nd edition, 30 sheets, (3rd quarter)

Considers basic theory and design of videofrequency amplifiers. Analyzes operation of most common amplifier circuits, circuits for fixing initial signal level, antinoise correction circuits, and others. Sets up calculation methods using frequency and transient characteristics for many different circuits, calculations for single-stage transistor amplifiers with diverse hookups. Describes operation and calculations for amplifiers with distributive parameters. Considers constructional details for amplifiers, sources of parasitic feedback and countermeasures, and tuning and testing of videofrequency amplifiers. Suitable as a college textbook.

Orlovskiy, E.L., Khalfin, A.M., Khazov, L.D., Zavarin, G.D., Krusser, B.V., and Shchelovanov, L.N., Theoretical Bases of Electrical Image Transmission (television and phototelegraphy) under edit. A.V. Tarantsov, 35 sheets, (3rd quarter)

Considers processes occurring in television and phototelegraphic transmission, communication channels and receivers. A unique feature of this book is the attempt to treat television and phototelegraphy as branches of a single technology of electrical image transmission and as having a common theoretical base. A textbook for radio-engineering faculties.

Saibel', A.G., Fundamentals of Radar, 20 sheets, (1st quarter)

Considers principles and methods of fixing the location of an object, measurements of distance and direction, moving-target selection, translation of radar images, basic radar equipment and means for raising noise immunity; a college textbook.

Chernyy, F.B., Propagation of Radio Waves, 20 sheets, (4th quarter)

Presents latest theoretical and experimental data on free propagation of radio waves, particularly in the troposphere and ionosphere. Great attention given to practical matters: calculation and construction of visibility patterns for radar stations, effect of various factors on visibility zone, analysis and calculation of errors in determining coordinates of an object, reflections from earth's surface, refraction, etc.; a college textbook on radar profiles.

Scientific-Technical Literature. Monographs

Bamdaz, A.M. and Savinovskiy, Yu.A., Filter Chokes in Radio Apparatus, 6 sheets, (3rd quarter)

Presents basic information concerning characteristics, construction, technological preparation, testing methods and filter-choke applications, with general engineering methods used in calculations. Specific chokes are examined.

Appendix gives collated tables of typical filter chokes for radio apparatus and material necessary for calculations.

Bychkov, S.I., Safarov, R.T., and Vurenin, N.I., Frequency Stabilization for UHF Oscillators, 16 sheets (4th quarter)

The book offers a systematization and generalization of work in the field of frequency stabilization of decimeter and centimeter range oscillators, and certain original

results from the authors' research. Sets forth requirements for stability of UHF oscillators and comparative appraisal of several methods; analyzes in detail parametric stabilization, synchronization methods for stabilization and automatic frequency control. Examples of application are given.

Weisfloch, A., Network Theory and Measurement Techniques in the Microwave Region, transl. from German, under edit. M.A. Silaeva, 22 sheets, (2nd quarter)

Monograph gives bases of method developed by author for study of UHF devices with short-circuit pistons. Considers application of this method to measurement of parameters of various radio apparatus and to matching of impedances.

Vinitskiy, A.S., Outline of Radar Principles for Continuous Propagation of Radio Waves, 20 sheets, (1st quarter)

A systematic presentation of initial assumptions and equations, common for radar in presence of continuous and pulse radiation; makes more precise classification of radar signals and reception methods; considers radar location of single targets under continuous radiation, including use of Doppler effect, characteristic circuits and operating regime of FM radar units and certain special circuits (double frequency modulation, etc.)

Subjects of radar fixing of several targets, sequential and parallel analysis of range spectra, distance scanning and gating in FM radar units are considered along with radar operation in presence of large scattering surfaces, operating principles of FM altitude indicators, autonomous velocity gauges and airplane drift-angle indicators, calibration of radar sets for velocity and distance, and many other special subjects.

Design of Large Systems, transl. from English, under edit of G.N. Povarov, 35 sheets, (3rd quarter)

Authors treat complications as separate phenomena and discuss certain general methods of overcoming difficulties connected with systems of complex design.

Gusev, V.P., Technology of Production of Radio Apparatus, 20 sheets, (1st quarter)

Deals with basic processes characteristic of production of radio-electronic apparatus, preparation, assembly and tuning of apparatus and individual parts with recommendations on choice of optimal regimes. Gives description of basic technological processes in preparation of wired details, capacitors, resistors, various elements of UHF circuits and wiring processes (including printed circuits) etc.

Dodik, S.D., Semiconductor Voltage and Current Stabilizers 6 sheets (3rd quarter)

Covers stabilization of supply voltages and currents and reference voltage stabilization in automation and remote control.

Middleton, D., Introduction to Statistical Communication Theory, in 2 volumes, transl. from English under edit. B.R. Levin, 80 sheets (3rd or 4th quarter)

A monograph devoted to applications of theoretical probability methods to study of diverse physical phenomena, holding an important place in design analysis of many radio technical systems.

First half of book contains theory of random processes, with main emphasis on radio-engineering applications. Second half is devoted to AM and FM systems, linear filtering, and study of reception based on statistical decision theory; special attention is given to systematic and complete consideration of construction methods for optimal systems and comparisons with nonoptimal systems: includes about 300 problems.

Morugin, L.A., Pulse Devices with Delayed Feedback, 9 sheets, (2nd quarter)

Research on basic properties of delayed-feedback systems and possible applications to pulse shaping and conversion, generation, amplification and separation of pulses with noise backgrounds; a mathematical analysis of transient processes and spectral characteristics of delayed-feedback systems is given.

Semiconductor Devices and Applications (collection) under edit. Ya.A. Fedotov, Nos. 7-8, 30 sheets (2nd and 4th quarter)

Takes up following subjects: physical processes in semiconductor instruments, production technology, parameters and characteristics of semiconductor devices, apparatus and methods of testing, operation of devices in various electronic circuits, description of circuits.

Application of Semiconductors to Computer Technique (collection) under edit. B.A. Tar-eyev, 28 sheets (4th quarter).

Publishes reports from seminar, Conference on Semiconductor Applications to Digital Computers held by A.S. Popov Scientific Society for Radio Engineering and Telecommunications. (March, 1960)

Gives physical bases of pulse-regime semiconductor operation and describes static semiconductor elements, amplifiers, and dynamic elements.

Radio Parts and Reliability Problems, transl. from English under edit. B.A. Tareev, 23 sheets (1st quarter)

Contains material on radio-electronic parts and their reliability, including causes of breakdown, determination and measurement methods for the "reliability" parameter, technical and economic considerations. Gives classification and general data on all kinds of resistors, analysis of capacitor operation and classification of basic types.

Stratonovich, R.L., Selected Topics in Fluctuation Theory, 30 sheets (1st quarter)

Discusses mathematical apparatus employed in study of fluctuation in various instruments, typical cases of the effect of signal and fluctuation on linear and nonlinear systems, and effect of signal and noise on radio receivers; analyzes operation of self-oscillators in presence of fluctuation; gives results of investigation of fluctuation peaks and their effect on relay operation, and solution to problem of selecting optimal instrument parameters in presence of fluctuation.

Tipugin, V.N. and Veitsel', V.A., Radio Control, 30 sheets (4th quarter)

Theory and calculations for radio devices used in guidance of missiles of various design; gives an analysis of transfer functions for radio links and appraisal of guidance errors occasioned by noise effects in the channel, variation in transfer function due to noise, and radio-telemetric systems for transmission of information from missiles.

Fialko, E.I., Meteor Observations with Radar, 6 sheets (1st quarter)

Presents basic information on radar tracking and study of meteors from material published in foreign and Soviet literature. Delves into radio astronomy of meteors and certain radiophysical, geophysical and radiotechnical problems connected with meteor observation; a voluminous bibliography is included.

Shchukin, A.N., Dynamic and Fluctuation Errors in Guidance, 10 sheets (1st quarter)

Given over to determination of physical nature, character and magnitude of deviations of real guided objects from ideal trajectories, errors inherent for the most part in their design.

Guided objects are thus seen as single systems possessing limited number of parameters which determine magnitude of errors under different states of motion of the objects. Methods are given for determining these parameters from experimental data.

Handbook Literature

Bergel'son, I.G., Parol', N.V., Daderko, N.K. and Petukhov, V.M., Reliable Receiver Amplifier Tubes, 20 sheets (4th quarter)

Side by side with basic electrical characteristics and parameters, economic facts and reliability data on modern receiver-amplifier tubes is presented. Recommendations are made on tube use with a view toward increasing reliability of apparatus.

STATE PRESS FOR COMMUNICATIONS AND RADIO (SVYAZ'IZDAT)

Textbooks and Reference Material

Abolits, I.A., Basik, I.V., et al. Long-Distance Telephony, 32 sheets, 10,000 copies (4th quarter)

Contains basis of a course in long-distance service; organizational principles channel construction and communication transmission; noise and distortion in long-distance lines, construction principles for terminals and apparatus, and rooms for linear apparatus; fundamentals of design of long-distance lines; intended for electrical engineering students in institutes.

Divnogortsev, G.P., Novikov, V.A., and Farber, Yu.D., Long-Distance Apparatus, 30 sheets, 12,000 copies (2nd quarter).

Considers construction principles for apparatus used in high-frequency aerial and cable telephone lines; intended for students at technical communications schools.

Collection, under edit. N.I. Chistyakov, Radio Communication and Broadcasting, 25 sheets, 25,000 copies. (3rd quarter)

Deals with organization of broadcasting and communication, operational principles of electronic and ionic devices, amplifiers, physical bases of radio propagation theory

and operational principles of radio transmitters and receivers, television stations, multiple radio-relay lines and relay networks; aimed at students in electrical engineering institutes who do not specialize in radio.

Koshcheyev, I. A., and Rez'yakov, A. P., Fundamentals of Electrical and Long-Distance Communication, 29 sheets, 10,000 copies (2nd quarter).

Presents basic state of wire communication theory, conditions for transmission of signal over homogeneous and composite circuits, theory of basic two-terminal pair networks, principles of construction and multiplexing of interurban cable and overhead lines, and basic information on apparatus and long-distance channels; intended for students of radio-engineering faculties at electrotechnical communications institutes.

Mileykovskiy, S. G. and Kosolapenko, G. D., Special Measurements in Wire Communication, 20 sheets, 10,000 copies (1st quarter).

Problems are formulated which are soluble by measurement technique; measurement methods and principles of operation of basic instruments for measuring electrical quantities are described; measurement of parameters and characteristics of overhead and cable lines, multiplexing equipment and parts (at audio and high frequencies) and methods for detecting defective parts and apparatus are discussed, written for students in technical schools of communication.

Model', Z. I., Radio Relay Devices, 32 sheets, 25,000 copies (1st quarter).

Presents theory and calculations for tube oscillators, theories of amplitude, phase and frequency modulation and telegraph keying; considers characteristics and special features of long -, medium -, and ultrashort-wave transmitters and examines principles of operation of centimeter and decimeter wavelength oscillators, klystrons, magnetrons, and traveling-wave tubes; for technical communications schools.

Scientific-Technical Literature

Aizenberg, G. Z., Short-Wave Antennas for Nation-Wide Networks, 2nd edition, 40 sheets, 10,000 copies (4th quarter).

Treats theory of radiation and reception of radio waves, electrical parameters of receiving and transmitting antennas, structural principles of short-wave antennas, engineering design methods, technical use and tuning of horizontal and vertical vibrators, synphasic, multiple frequency, rhombic, and traveling wave antennas, and those with controlled directional characteristics, and the construction of feeders, coaxial lines and commutation systems for antennas and feeders.

Dreizen, I. G., Electroacoustics and Sound Broadcasting, 30 sheets, 10,000 copies. (3rd quarter)

Presents basic physics and laws of physiological psychology governing rational choice of qualitative broadcasting indexes, and rational structures and systems for sound absorption and insulation; considers dynamics and parameters of modern acoustical apparatus and clarifies architectural considerations in design of halls and radio studios, chiefly in their application to theory and practice of sound transmissions.

Efimov, I. E., Multilayer Wire Communication, 6 sheets 5000 copies (1st quarter)

Considers theoretical bases of calculation of electrical parameters of multilayer wires, transmission parameters of communication circuits using tri- and bimetallic conductors, and nonlinear properties of bimetallic wires containing ferromagnetic materials.

Zhondetskaya, O. D. and Polonskiy, N. B., Systems for Suppressing Complex Interference from Industrial Plants, 3 sheets, 15,000 copies, (2nd quarter)

Gives analysis of industrial sources of noise in radio reception, recommendations and practically tested noise-suppression circuits for incorporation in both currently operating and planned factories.

Krylov, G. M., Logarithmic Amplifiers, 8 sheets, 10,000 copies (2nd quarter)

Considers theory, calculations and design procedure for amplifiers with nonlinear amplitude characteristics obeying logarithmic laws.

Rizkin, A. A., Semiconductor Amplifiers, 8 sheets., 10,000 copies (1st quarter)

Presents basic circuit theory for semiconductor amplifiers (equivalent circuits internal feedback, neutralization, noise) and indicates methods for designing them.

Reference Collections on Communications Technology

Collection, under edit. S. A. Vladimirov, New Developments in the Field of Control and

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Presents basic information on transportable checking apparatus for studying microwave propagation, highly sensitive field-strength meters, devices for measuring characteristics of time delay networks such as IBZ-1, IBZ-2 and (in video range) IBZ-T, instruments for measuring noise power in multichannel radio relays with 240, 600, and 900 channels in line, IFT device for measuring phase angle in videofrequency range, intermediate frequency sweep oscillator and GMI-23 oscillator generating millimicrosecond pulses and standard frequencies.

Series: lectures in Communications Technology

Belousov, S.P., Directional Antennas, 4 sheets, 7,000 copies (4th quarter)

Considers directive gain and amplification factor, anti-fading properties of single-wire, traveling-wave antennas, constructional details for double-wire, vertical, asymmetric, traveling-wave antennas, steerable antennas, goniometric antennas, systems made from three vertical vibrators and linear phasing devices; gives recommendations for choice of directional antennas for work in 200-2000 meter range.

Daniel'-Bek, V.S., and Roginskaya, I.S., Thermoelectric Generators, 3 sheets, 7000 copies (2nd quarter)

Discusses dynamic principles of thermoelectric generators, physical properties of thermoelectronic materials, calculations, construction, technology and characteristics of thermocells and batteries, construction and characteristics of details, new types of generators with increased power, operational data, technical and economic indexes and fields of application.

Znamenskiy, A.A., Adjustable Artificial Lines in Wire Communications, 3 sheets, 6000 copies (4th quarter)

Covers adjustable artificial lines (AAL) and their application to multichannel apparatus, basic characteristics, AAL circuits with: ordinary equalizers, branched equalizers, voltage dividers, distortion correctors, and frequency-response potentiometers; calculations are included.

Sukhodoyev, I.V., K-3 Semiconductor Communication Systems, 3 sheets, 8000 copies, (4th quarter)

Discusses principles of construction, apparatus characteristics and channels of type K-3, three-channel, high frequency, semiconductor telephone systems; shows circuit and skeleton diagrams of terminal and tandem stations, remote-feed blocks and signalling circuits

Khatskelevich, V.A., Specific Features and Operational Calculations for New Tube Oscillators, 2.5 sheets, 10,000 copies (2nd quarter)

Concerned with features of a new series of triode oscillators, in particular, thermal regime and anode and grid current characteristics; gives critical analysis of existing calculation methods, indicating their unsuitability for the new tubes and offers a simpler method based on equivalent parameters.

Sheremetev, A.V., and Zhitkevich, R.G., Treatment of Measurements of Electrical Characteristics in Long-Distance Telephony by the Methods of Mathematical Statistics, 2.5 sheets, 6000 copies (1st quarter)

Presents a brief introduction to probability theory (distribution functions, empirical and mathematical probability, mathematical expectation, normal distribution, etc.) and recommends subjecting long-distance telephony calculation results to statistical treatment.

Radio Amateur's Literature

Zherebtsov, I.P., Radio Engineering, 5th edition, 30 sheets, 100,000 copies (3rd quarter)

Gives basic understanding of radio broadcasting and communication; considers construction and operating principles of oscillatory circuits, vacuum tubes, semiconductor devices, rectifiers, low-frequency amplifiers, receivers and antennas, transmitters; discusses radio wave propagation and basic principles of radio measurements.

Handbook Literature

Collection, under edit. G.S. Lyubskii, Engineering-Technical Handbook of Electrical

Communication, 30 sheets, 10,000 copies (3rd quarter)

The book gives reference material on power station equipment (semiconductor and ion rectifiers, DC and AC transformers, electrical machines, internal combustion engines, batteries, distributors and transformer substations, remote-supply apparatus, etc.), distributing networks and high-and-low-voltage lines, supply systems and automation of wire and radio communication setups.

OBORONGIZ

Textbooks and Student Manuals

Belotserkovskiy, G.V., Radar Devices, 20 sheets, 15,000 copies (1st quarter).

Describes general principles, electrical circuits and structural features of certain kinds of ground and airborne radar stations of diverse function. Gives analysis and critical appraisal of station features, contrasting different structural and circuit variants; considers ground control and observation, airborne stations, airplane altimeters and distance gauges, navigation and blind-bombing units; a textbook for technical students.

Seleznev, V.P., Navigational Devices, 32 sheets, 10,000 copies (1st quarter).

Presents theoretical bases and describes material means for aerial navigation, astronomical orientation relative to earth and in interplanetary space. Special attention is paid to single-course systems, velocity and altitude measures, Doppler principle in velocity measurement, computers for trajectories and astronomical orientation; textbook for aviation students of higher technical schools.

Scientific-Technical Literature

Belevtsev, A.T., Potentiometers, 23 sheets, 25,000 copies (4th quarter).

Selected and systematized material on theoretical bases, calculations and design of potentiometers, preparation technology, and applications to devices for fulfilling mathematical operations and the testing of long-distance transmitters. Gives information on preparation processes for multithread and metallic film potentiometers.

Studies in Physics and Radio Engineering, No. 8 (Trudy Moscow Physicotechnical Institute) 10 sheets, 3000 copies (4th quarter).

Collection, devoted to theoretical and experimental studies in radio-wave propagation, pulse technique, cathode electronics and physical chemistry.

Kitaigorodskii, Yu.I., Ultrasonic Apparatus and Technical Applications, 12 sheets, 5,000 copies, (4th quarter).

Presents basic theory and engineering calculations for ultrasonic apparatus (oscillators and converters), analysis of various electrical circuits and apparatus construction, recommendations on choice of optimal solutions and necessary equipment parameters for technological processes.

Considers methods of measuring ultrasonic-field characteristics and operating regimes describes the measuring instruments themselves, and gives a classification and brief characteristics for various technological processes using ultrasound.

Krylov, V.A. and Solovei, A.P., Labor Safety in the Operation of High and Ultrahigh-Frequency Installations, 5 sheets, 10,000 copies (4th quarter).

Describes high-frequency power generators and effect of electromagnetic fields on the human organism, and, also, effect of soft x-rays from high-voltage vacuum tubes. Discusses technical problems in safety and industrial sanitation in operation of high and ultrahigh frequency setups.

Mikhailov, F.A., Free Vibrations of Linear Systems with Varying Parameters, (Trudy, MAI), 16 sheets, 30,000 copies (1st quarter).

Present theoretical bases of oscillations in linear systems with varying parameters, investigates stability of vibrations and analyzes their characteristics in a finite time interval.

Parametric Amplifiers with Diode Capacitors, collection, under edit. A.P. Belousov (Trudy MAI), 10 sheets, 30,000 copies, (3rd quarter).

Sets forth calculation theory for paramagnetic amplifier with diode capacitors. Formulas

are introduced for calculating amplification, bandwidth, noise factor, matching, etc. Applied to single and double circuit amplifiers working with and without circulation. Presents formulas for calculating and appraising twelve parametric amplifiers.

Semiconductor Materials and Instruments, in 4 volumes, transl. from English title "Transistor Technology," under original edit. G. Bridgers, G. Scaff, G. Sheib and F. Bionde.

First volume: Technique of Preparing Semiconductor Materials, under edit. M.I. Iglitsyn, 20 sheets, 10,000 copies (1st quarter).

Describes basic technology of semiconductor materials (Ge and Si) apparatus and processes involved in obtaining homogeneous, good-quality monocrystals with given physical properties. Especially concerned with obtaining of p-n junction monocrystals and considers modern quality control in semiconductor production.

Second volume: Calculation and Design of Semiconductor Instruments, under edit. G.D. Glebov, 25 sheets, 20,000 copies (4th quarter).

Gives construction principles and engineering calculations for wide range of semiconductor instruments (diodes, transistors, tetrodes, switches, field-controlled devices, and converters). Considers noise in junction-type semiconductor instruments and ways to reduce it, and phenomena taking place on semiconductor surfaces which have negative effect on stability and reliability of operation.

Third volume: Production of Semiconductor Instruments, under edit. G.D. Glebov, 22 sheets, 10,000 copies (4th quarter).

Principles for organizing production of devices and most important technical operations in work with semiconductor materials are given; describes special technological operations (cutting, polishing, galvanizing, creation of p-n junctions, etc.) and production methods for most common types of semiconductor devices: point-contact, alloy, diffusion, surface barrier.

Fourth volume: Methods of Measuring Semiconductor Instrument Parameters, under edit. M.I. Iglitsyn, 20 sheets, 15,000 copies (1st quarter).

Presents general principles and performance criteria of semiconductor devices with brief analysis of operation under small-and-large-signal and pulse regimes; describes methods and circuits for measuring parameters under laboratory and production conditions; presents American testing standards. Reliability and stability are considered.

Handbook Literature

Panasenko, V.D., Elements of Control Apparatus and Computer Technique, a Designer's Handbook, 2nd edition, revised and enlarged, 14 sheets, 10,000 copies (3rd quarter).

Presents general information on basic characteristics and circuit diagrams, construction and technical data on basic elements of automatic devices and computer technology, e.g., relays, potentiometers, photoelectric pickups, electronic and magnetic amplifiers, amplidydes, AC and DC motors, tachogenerators, rotating transformers, operational amplifiers, triggers, shaping devices (blocking generators, multivibrators, amplifier-shapers), etc.

MILITARY PRESS

Textbooks and Reference Material

Davydov, S.L., Zherebtsov, I.P. and Levinzon-Aleksandrov, F.L., Radio Engineering 3rd edition, corrected and enlarged, 25 sheets (2nd quarter)

A textbook on military communications.

Slutskiy, V.Z., Fogel'son, B.I., Levichev, V.G. and Yagodin, O.G., Fundamentals of Radar and Radio Engineering. Indicators, Rectifiers and Semiconductor Devices, 25 sheets, (2nd quarter)

Designed for college students of radio engineering.

Scientific-Technical Literature

Baranul'ks, V.A., New Developments in Radio Broadcasting, 9 sheets, (2nd quarter).

Considers practical utilization of the latest achievements in radio wave propagation applied to communication. Presents experimental methods for determining operating frequency

and communication zone, material on practical use of radio astronomical data and data required for reception of information from satellites.

Vereshchagin, E.M., Antennas and Radio Wave Propagation, 20 sheets, (3rd quarter).

Considers fundamental properties of antennas and radio waves, construction, operation and electrical characteristics of antennas and transmission lines encountered in military communications. Characteristic features of radio wave propagation are presented; practical recommendations are made on choice of antenna and wavelength for communication involving mobile stations.

Pashkov, A.N., and Korsakov, V.P., Testing of Radio Measuring Instruments, 25 sheets, (2nd quarter)

Takes up the theory of radio measurements, methodical basis of testing and construction of instruments and gives data for several exemplary installations and measurement methods.

Smirnov, G.D. and Gorbacher, V.P., Radar Systems with Active Response, 7 sheets, (2nd quarter).

Presents basic principles of operation of radar systems with active response, their applications to identification, navigation, fixing the coordinates of unmanned objects, and telemetry; certain subjects concerning ultralong-distance radio communication are advanced.

Tikhonov, I.I. and Sluchenskiy, B.F., Radar and Its Applications, 15 sheets (1st quarter)

Presents physical bases of radar, tactical and technical features of radar stations of diverse purpose. Gives fundamentals of military exploitation of radar for solution of various field problems. Indicates measures for combatting "jamming" by the enemy.

Series: Technical Communications Library

Anisimov, A.G., Single-Band Communication, 5 sheets, (2nd quarter).

Considers fundamentals of single-band radio communication, operation of certain circuit elements, methods of sending and receiving the signal, distortion, noise stability in reception and some single-band instruments.

Yagodin, V.P., Printing Radio Communication, 6 sheets, (4th quarter)

Presents basic principles and physical processes in individual parts of apparatus. Considers single- and double-channel systems in radio telegraphy, multichannel printing over single-band radio channels, and certain details in use of printing radio lines.

Handbook Literature

Rapoport, Z.G., and Borbov, K.E., Materials for repair of Radio Facilities (Brief Handbook), 15 sheets, (2nd quarter).

Presents basic characteristics of most common materials used in repair of radio engineering facilities.

Trunkovskiy, L.E. and Kuznetsov, Yu.L., Control Cables, 17 sheets, (2nd quarter)

Handbook on installation and use of control and special cables.

Popular Science Literature

Gerasimov, D.N., Klystron, 3 sheets (1st quarter).

Presents operational principles and various constructional types of klystron; gives electrical characteristics and indicates fields of application of transit and reflex klystrons.

Federov, E.K., Soviet Satellites and Space Rockets, 4 sheets, (1st quarter).

Author tells of tremendous strides made by Soviet scientists and engineers in launching satellites and space rockets.

SEA TRANSPORTATION PRESS

Textbooks and Reference Materials

Koval'chuk, V.S., Fundamentals of Radio Engineering, 15 sheets, 5000 copies (1st quarter)

Textbook for students of navigation in maritime schools.

Krylov, N.N., Theoretical Bases of Radio Engineering, 3rd edition. 30 sheets, 3000 copies (2nd quarter)

Intended as a textbook for students in radio faculties.

Pisarev, V.A., Radio Equipment for Sea Vessels, 22 sheets, 5000 copies (1st quarter).
Textbook for radio engineering specialists in maritime schools.

Polozhintsev, V.A., Bairashevskiy, A.M. and Aizinov, M.M., Fundamentals of Radio Technology and Navigation Devices, 25 sheets, 5000 copies (3rd quarter)

Gives physical bases of radio technology and radio electronics; considers instruments and principles of operation of radio navigation devices; audible and automatic visual radio direction finders, radio beacons, phase-pulse and radio navigation systems; presents fundamentals of radar and instruments and operation of marine radar stations. The book may be used as a textbook for navigation faculties of marine engineering colleges.

Technical Science Literature

Geophysical Collection, under edit. A.P. Nikol'skii and A.I. Ol', 10 sheets, 1000 copies, (3rd quarter).

Contains articles concerned with radio wave propagation at high latitudes, magnetospheric disturbances in the Arctic and Antarctic and their relation to solar activity.

Davydov, P.S., Ivanov, V.G., Blaibas, L.A. and Loss P.M., The Marine Radar Station "Donets", 16 sheets, 10,000 copies (2nd quarter)

Acquaints the reader with basic construction, electrical circuits and principles of regulation of the new marine radar navigation station "Donets".

Koval'chuk, V.S., Fundamentals of Radio Engineering, 4 sheets, 2,000 copies (2nd quarter).

The brochure briefly presents the necessary technical background for the study of radio navigation instruments.

Ionospheric Observations of the Third Cross-Continental Antarctic Expedition, under edit. G.N. Gorbushin, 15 sheets, 1000 copies (3rd quarter)

Publishes tables and graphs of ionospheric parameters from data collected since 1958 at "Mirny" and Vostok" stations, for use in design and development of long and ultralong radio lines over polar regions.

Observations from the Drifting Stations SP-6 and SP-7 (1957-1958) on the Earth's Magnetic Field and Ionospheric, under edit. V.M. Driatskii, 30 sheets, 1000 copies. (2nd quarter)

Presents ionospheric and magnetic observations, including tables of hourly magnitudes of critical frequency and effective height of base layers of ionosphere, minimum reflection frequency and conversion factors for magnetic dip. Material on terrestrial magnetism contains tables of hourly vertical and horizontal components of earth's magnetic field, declination and magnetic activity

Sea Navigation and Communication, 8 sheets, 1000 copies (4th quarter)

Presents theoretical developments from Central Scientific Research Institute of the Navy in automation of navigation, design of gyrocompasses, logs, radar and radio navigation systems, hydroacoustics and radio communication.

SUDPROMGIZ

Technical Science Literature

Berman, Ya. I. and Vlasov, V.N., Planning and Preparation of High Frequency Facilities for Radar Stations, 24 sheets, 20,000 copies, (1st quarter).

Presents theory of design and construction of waveguides and coaxial installations, cavity resonators and cavity resonators and centimeter-range antennas. Gives data on design and testing of usual high-frequency apparatus and Soviet and foreign technological achievements in this field.

Kogan, N.L., Mashkovskiy, B.M. and Tsybizov, K.N., Theoretical Fundamentals and Design of Waveguide Channel Elements, 25 sheets, 20,000 copies (2nd quarter).

Presents design of basic elements of complex waveguide channels. Calculations are made on an electrodynamic model with subsequent solutions by usual methods of mathematical physics; replacement circuits are set up; calculations are produced for plane-transverse inhomogeneities, smooth periods, antennas and waveguides with switches, filters, rotating junctions; statistical properties of complex waveguide routes and problems of matching, design of circuits containing magnetized ferrites are considered.

Peresada, V.P., Radar Visibility of Objects at Sea, 10 sheets, 15,000 copies, (2nd quarter)

Deals with basic modern methods for calculating field of secondary radiation from bodies and surfaces, and practical calculations required in engineering. Discusses experimental methods of measuring secondary fields. Tables and nomograms are presented to aid calculation (by Academician V.A. Fok's method) of secondary radiation from marine objects.

Perov, V.P., Design of Radar Servosystems Taking Random Effects into Account, 6 sheets, 20,000 copies (2nd quarter).

Presents methods for calculating effect of various kinds of interference on accuracy and range of radar stations employing linear scanning in a circular-coverage regime. Simple methods are introduced for determining optimal structural circuits for servosystems and potential accuracy in calculating coordinates.

Sidorenko, V.V., Maleev, P.I. and Dolgirev, E.I. Detectors of Ionizing Radiation, 14 sheets, 10,000 copies (1st quarter).

Considers physical phenomena occurring in detectors; describes operation and testing methods. Special attention is devoted to scintillation counters and semiconductor detectors, and questions of practical application of detectors in various dosimetric circuits.

Herwood, et al., Effect of Nuclear Radiation on Materials, transl. from English, 25 sheets 10,000 copies (2nd quarter).

This is a monograph containing 11 reports read at Baltimore University (USA). Contemporary opinion on the effect of nuclear radiation on solids is presented; several topics relate to experimental technique in radiation studies and analysis of current experimental data, consideration of radiation effects in solid dielectrics and semiconductors, organic compounds and polymers, is given. A large bibliography is included.

Yakovich, N.S., Chelnokov, V.E. and Geifman, M.P., Junction Transistors, 12 sheets, 20,000 copies (2nd quarter).

Presents theoretical basis of semiconductor physics and data on various electronic circuits containing crystal triodes.

A description is given of several crystal triode devices used on ships.

Handbook Literature

Kochkina, N.N. and Ovsishcher, P.P., Handbook of Semiconductor Diodes and Triodes, 13 sheets, 35,000 copies (1st quarter).

Contains brief technical data and instructions for use of most widely distributed semiconductor instruments of Soviet make. Divided into two parts, the first part deals with diodes, the last, with triodes.

ATOMIZDAT

Textbooks and Reference Material

Collection, under edit. K.D. Sinel'shchikov, High-Frequency Heating of Plasma, 10 sheets 6000 copies (4th quarter).

Gives review of experimental and theoretical work devoted to high-frequency properties of plasmas and heating methods. Results of investigations conducted at Physicotechnical Institute, Academy of Sciences, Ukrainian SSR; Institute of Atomic Energy, Academy of Sciences, USSR, Physics Institute Academy of Sciences, USSR, and other Soviet and foreign institutes, are utilized. Common parametric and nonlinear resonance in plasma are investigated, a comparison of different methods of high-frequency heating is made and results of experiments on electron and ion resonance in plasma are described.

Designed for students in the physics faculty of higher schools.

Faynberg, Ya. B., Reactions of Streams of Charged Particles with Plasma, 10 sheets, 6000 copies (4th quarter)

Reviews theoretical and experimental work in field; takes up question of origin and development of instabilities on reaction of charged-particle streams with confined and free plasma, both in presence and absence of external magnetic fields. Spectrum of excited vibrations, growth increment, and loss of energy of stream moving through plasma are determined; effect of particle-plasma interaction on conductivity, and, especially, diffusion

diffusion processes, in plasma are examined; questions concerning excitation of longitudinal waves of large amplitude (nonlinear waves) and reaction of slow waves with moving plasma, and other questions, are considered.

Intended for students in physicomathematical faculties.

Scientific Literature

Brown, S., Fundamentals of Plasma Physics, transl. from English, 21 sheets, 7000 copies (3rd quarter)

A textbook course in plasma physics, conducted by the author at Massachusetts Institute of Technology (USA). Presented material is basic for understanding the several processes associated with gas-discharge phenomena, controlled thermonuclear reactions, studies of upper layers of atmosphere, ionization reactions, etc.

Dangee, G., Electrodynamics of Space, transl. from English, 10 sheets 7000 copies, (1st quarter).

Presents fundamentals of magnetohydrodynamics, chiefly applied to astrophysics and geophysics. Principal attention is given to basic physical considerations and qualitative conclusions deducible from them. Presentation of basic information on magnetohydrodynamic phenomena on the sun and in upper atmosphere of earth hold special interest.

Komel'kov, V.S., et al., Technique of Obtaining Large Current Pulses and Magnetic Fields, 16 sheets, 5000 copies (3rd quarter).

Presents principles of contemporary technical and theoretical methods of designing installations for high fields and currents. Gives experience of Soviet and foreign (USA, England, Germany) institutes in this field.

Rukhadze, A.A., and Silin, V.P., Electromagnetic Properties of Plasma and Media Similar to Plasma, 20 sheets, 6000 copies (4th quarter).

Considers electromagnetic properties of plasmas, metals and molecular crystals. Brings forth basic results obtained in a great quantity of work performed by Soviet and foreign scientists.

Fuenfer, E. and Neiert, H., Counter Tubes and Scintillation Counters, transl. from German, 22 sheets, 10,000 copies (3rd quarter).

Deals with modern methods of registering radioactive radiation, detectors and radio-electronic instruments. Considers properties and applicability of diverse forms of gas-discharge counters, Cherenkov counters, photoelectric multipliers and crystals (scintillation counters), technical problems in production of gas-discharge counters. Describes basic kinds of radioelectronic apparatus currently used for registration - pulse amplifiers, amplitude analyzers, etc. A voluminous bibliography is included.

Popular Science Literature

Morgulis, N.D., Thermoelectronic (plasma) Energy Converter, 5 sheets, 30,000 copies, (3rd quarter).

Frank-Kamenetskiy, D.A., Plasma - the Fourth State of Matter, 8 sheets, 30,000 copies, (2nd quarter).

MOSCOW UNIVERSITY PRESS

Textbooks and Reference Material

Brandt, A.A., Installation and Tuning of Radio Circuits, 3rd edition, 22 sheets, 50,000 copies (4th quarter).

Contains descriptions of input circuits of measuring apparatus and various parts used in radio. Considers theory of phenomena occurring in radio circuits, and design methods for most characteristic elements. Takes up adjustment of amplifiers, oscillators, multivibrators and other apparatus used for obtaining characteristics of transistor circuits with allowance for effect of input used in measuring. Circuits are given for semiconductor triodes, design methods and instructions for installation.

Intended for students at universities and higher technical schools.

Grigor'yants, V.G., Basic Characteristics of Radar Stations, 8 sheets, 10,000 copies (4th quarter).

Presents physical principles of radar observation and determination of coordinates of objects, operating regime, composition, element interaction and special features of various types of stations, contents, choice and interconnection of basic characteristics and parameters of radar apparatus.

For students of physics colleges and higher schools.

Malitskiy, A.N., Units of Measurement of Electrical and Magnetic Quantities, 2.5 sheets, 25,000 copies (1st quarter)

A brief review of the most common systems of units for electrical and magnetic dimensions.

Regel'son, L.M., Physical Processes in Blocking Generators, 8 sheets, 10,000 copies, (4th quarter).

Considers typical variants and operating circuits of blocking generators, including problems of synchronization and frequency dividing. Principal attention is given to physical nature of processes; fundamentals of circuit design are given; directed to students of higher schools.

Semenov, A.G., Theory of Electromagnetic Waves, 12 sheets, 10,000 copies, (4th quarter).

Takes up general laws of electromagnetic wave processes; presents theory of plane waves, theoretical information on wave propagation in gyrotropic media, theory of cylindrical waves, propagation in presence of waveguides, vibrations in cavity resonators.

Book is intended for radiophysical and radio engineering specialists.

Chechernikov, V.I., Magnetic Measurements, under edit. E.I. Kondorskiy, 25 sheets, 10,000 copies, (3rd quarter).

Presents basic methods of studying magnetic properties of substances in constant and varying magnetic research methods developed in recent times; a student textbook

LENINGRAD UNIVERSITY PRESS

Radio Wave Propagation, Collection, 13 sheets, 5,000 copies, (2nd quarter).

Considers propagation of waves in ionosphere over a "flat" and spherical earth using pulse and stationary regimes. Presents a new analysis for electromagnetic field of dipole above flat earth; investigates wave propagation over laminar path and transient processes taking place during radiation and propagation of radio waves.

Fok, V.A., Lectures on Fundamentals of Quantum Mechanics, 8 sheets, 5,000 copies, (2nd quarter).

Revised lectures for an introductory course in quantum mechanics read by author at Physics Faculty of Leningrad University; basic discussion revolves around methodological questions in quantum mechanics.

Intended for students, candidates, and scientific workers.

KHAR'KOV UNIVERSITY PRESS

Gorelik, A.L., Electronic, Ionic and Semiconductor Devices, 15 sheets, 10,000 copies, (1st quarter)

Textbook for radiotechnical institutes and faculties.

STATE STANDARDS PRESS (STANDARTGIZ)

D.I. Mendeleev All-Union Scientific Research Institute of Metrology, Collections.

Research in the Fields of Pressure and Vacuum, 8 sheets, 30,000 copies (4th quarter)

Devoted to design and study of precision apparatus for measuring small, absolute gauge pressures.

Investigation of Error Assessment in Measurements, 8 sheets, 30,000 copies, (2nd quarter)

Considers questions of errors in various measurement fields generally and errors in linear measurements and radio engineering particularly.

Accurate Measurements of Current, Voltage and Power in Sonic and Ultrasonic Frequency Ranges, 9 sheets, 3,000 copies (4th quarter).

A systematized review of various means for measuring basic electrical magnitudes

at sonic and ultrasonic frequencies.

All-Union Scientific Research Institute of the Committee
of Standards, Measures, and Measuring Instruments.

Buldakova, R.I. and Kiparenko, V.I., Apparatus for Measuring Voltages at High and Ultrahigh Frequencies, 4 sheets, 5,000 copies (4th quarter).

Monograph presents critical review of current Soviet and foreign instruments for measuring voltage at high and ultrahigh frequencies; describes facilities and methods of calibrating and testing these devices.

Burdin, G.D., Methods of Measuring Dielectric Permittivity and Loss at Ultrahigh Frequencies, 12 sheets, 3,000 copies, (4th quarter).

Monograph contains description of standards and measures for magnetic units, contemporary methods of measuring voltages of constant and variable magnetic fields, methods of testing ferromagnetic and magnetic materials in alternating and direct currents, and methods for measuring magnetic flux.

All-Union Scientific Research Institute of Physicotechnical
and Radio Engineering Measurements. Collections.

Frequency Measurements, 12 sheets, 3,000 copies (4th quarter).

Discusses problems in the measurement of frequency of electrical oscillations and describes the operation of the State Frequency Service; considers methods of obtaining standard frequencies with quartz and molecular oscillators and deals with microwave frequency standards. Presents results of investigations on stability conditions in operation of quartz oscillators and frequency converters.

Collection includes questions of reception, transmission and measurement of standard frequencies, supplementary errors and correction methods in propagation of standard frequencies through electrical circuits and in radio.

Radio Measurements, 200 sheets, 3,000 copies (3rd quarter).

In collections (1 and 2) are presented articles on accurate measurement of power, voltage, current, field intensity, noise, fading, pulse and material parameters; errors in measuring devices are considered.

Testing of Radio Measurement Devices (collection of instructions and methods), 15 sheets, 3,000 copies (3rd quarter).

Contains 20 instructions and methods for testing measuring instruments, echo resonators, heterodyne frequency meters, oscillators, tube voltmeters, measures of small power, objective noise meters, etc.

"DOSAAF" PRESS

Popular Science and Technical Literature

Bunimovich, S.G., and Yailenko, L.P., Radio Transmission and Reception over a Single Sideband, 8 sheets, 50,000 copies (3rd quarter).

Collection, Best Constructions from the 16th Radio Amateur's Exhibition, 8 sheets, 50,000 copies, (2nd quarter).

Labutin, L.M., Receiving and Transmitting Apparatus for Amateur Radio Stations, 5 sheets, 25,000 copies (2nd quarter).

Svoren', R.A., Construction of an Amateur Broadcasting Receiver, 8 sheets, 50,000 copies, (4th quarter).

Trofimov, K.N., Interference in Radar Stations, 3 sheets, 25,000 copies (4th quarter)

Sheyko, V.P., Amateur Broadcasting Antennas, 3 sheets, 50,000 copies (2nd quarter)
Goskhimizdat.

Alekseyev, N.G., Prokhorov, V.A. and Chmutov, K.V., Applications of Electronic Instruments in Physicochemical Research, under edit. K.V. Chmutov, 25 sheets, 15,000 copies, (2nd quarter).

A handbook on application of electronic circuits to research in physical chemistry; describes Soviet-made parts and possible substitutes, manufactured instruments and how to use them.

"KNOWLEDGE" PRESS

Yagom, A.M., Information Theory

Brochure acquaints reader with fundamentals of modern information theory; describes research methods in storage and transmission and treats information theory as a branch of cybernetics. Considers basic directions for future development of computers and practical applications of theory of information to various fields of science, technology and culture.

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The total volume of books on radio engineering, electronics and allied fields marked for publication in 1961 comprises more than 6,000 sheets. Of these technical science constitutes over 4,00 sheets, (~ 68%), textbooks, 900 sheets, (~14%), handbooks 675 sheets (~11%), and popular science 425 sheets, (~7%).

Of the total volume, radio engineering's share comes to ~60% (more than 35,000 sheets), electronics ~22% (1300 sheets), and related fields (mathematics, physics, technology, general handbook literature) ~18%, over 1100 sheets.

The publishing houses for radioelectronics literature to be issued in 1961 are distributed in the following way: Gosenergoizdat, over 1500 sheets, Academy of Sciences, USSR Press, 700, Soviet Radio, 600 sheets, and Svyazizdat, 400 sheets.

INTERNATIONAL CONFERENCE ON QUANTUM ELECTRONICS

We have received a request from the organizing committee of the conference to notify our readers that the 2nd International Conference on Quantum Electronics will be convened in Berkeley, California, from March 23 to March 25, 1961. Main discussion will be centered on basic theory, latest progress and new lines of study in the field.

Methods of generating millimeter and shorter waves, coherent sources, amplifiers, fundamental research in matter and very high-frequency techniques will be discussed.

For information write to: Professor J.R. Singer, Chairman, Second International Conference on Quantum Electronics, Department of Electrical Engineering, University of California, Berkeley 4, California.

ALEKSANDR NIKOLAEVICH SHCHUKIN

(For His Sixtieth Birthday)

The 22nd of July, 1960, marked the sixtieth birthday of that outstanding Soviet scientist in the field of radio engineering, Academician Aleksandr Nikolaevich Shchukin.

On the 2nd of December, 1960, the Soviet scientific-technical community took note of this, and of his thirty-five years of activity in science, teaching and technical society work, at a conference organized by the Technical Science Division of the Academy of Sciences, USSR, the All-Union Scientific Soviet of Radio Physicists and Engineers of the Academy of Sciences, USSR, the State Committee on Radioelectronics of the Council of Ministers, USSR, the Institute of Radio Engineering and Electronics of the Academy of Sciences, USSR, the A.S. Popov Scientific-Technical Society of Radio Engineering and Electrical Communications, and other organizations.

In 1927, Shchukin graduated from the V.I. Ul'yanov (Lenin) Leningrad Electrotechnical Institute as a radio engineering specialist.

He had begun his scientific activity even as a student; from 1923 he worked in the Central Radio Laboratory of the Industrial Weak-Current Combine, directed by Professor D.A. Rozhanskiy, in the fields of high power generation in short waves and non-quartz frequency stabilization.

His scientific research was always closely bound to real problems in radio engineering. Shchukin's work in the late 'twenties' and early 'thirties' on theory, design, and experimental research with short-wave propagation won universal recognition.

His scientific interests are exceptionally diversified. Radio wave propagation, frequency stabilization, radio direction finding, noise stability of receivers, transient processes in complex circuits, radio communication systems, radar, remote control -- these are but a few of the fields to which A.N. Shchukin has made enormous contributions.

The scientific services of Shchukin have been given high rewards. In 1937 he defended his doctor's dissertation and in 1946 he was elected corresponding member, and in 1953 became an active member, of the Academy of Sciences of the USSR.

Besides his scientific activity, Shchukin, for many years after 1929, was a teacher and guided the students of many higher institutions. His work "Radio Wave Propagation" and the course of the same name which he taught for twelve years at the V.I. Ul'yanov Leningrad Electrotechnical Institute, played a very important role in preparing the radio engineering cadres of our land.

Shchukin combines the talents of a great theoretical scientist, experimenter, innovator and inventor, with those of an organizer and active leader in technical societies.

His services are highly appreciated. His fruitful activity has been rewarded many times by the government.

We wish our dear friend many more years of creative scientific, social and pedagogical work for the good of our country.

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